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(54) **LIGHT-EMITTING ELEMENT, LIGHT-EMITTING DEVICE, AND ELECTRONIC DEVICE**

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(30) **Foreign Application Priority Data**

Jun. 8, 2005 (JP) 2005-167620

(51) **Int. Cl.**

H01L 51/54	(2006.01)
H01L 33/42	(2010.01)
H01L 51/52	(2006.01)
H01L 51/50	(2006.01)

(52) **U.S. Cl.**

CPC ***H01L 33/42*** (2013.01); ***H01L 51/5262*** (2013.01); *H01L 51/5088* (2013.01); *H01L 2251/558* (2013.01)

(58) **Field of Classification Search**

CPC H01L 51/5052; H01L 51/506; H01L 51/5068; H01L 51/5088; H01L 51/5262

See application file for complete search history.

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Primary Examiner — Michael H Wilson

(74) *Attorney, Agent, or Firm* — Robinson Intellectual Property Law Office; Eric J. Robinson

(57) **ABSTRACT**

The present invention provides a light-emitting element, a light-emitting device and an electronic device in which an optical path length through which generated light goes can be changed easily. The present invention provides a light-emitting element including a light-emitting layer between a first electrode and a second electrode, and a mixed layer in contact with the first electrode; in which the light-emitting layer includes a light-emitting substance; the mixed layer includes a hole transporting substance and a metal oxide showing an electron accepting property to the hole transporting substance, and has a thickness of 120 to 180 nm, and when a voltage is applied between the first electrode and the second electrode such that a potential of the first electrode is higher than that of the second electrode, the light-emitting substance emits light.

12 Claims, 17 Drawing Sheets

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Fig.1

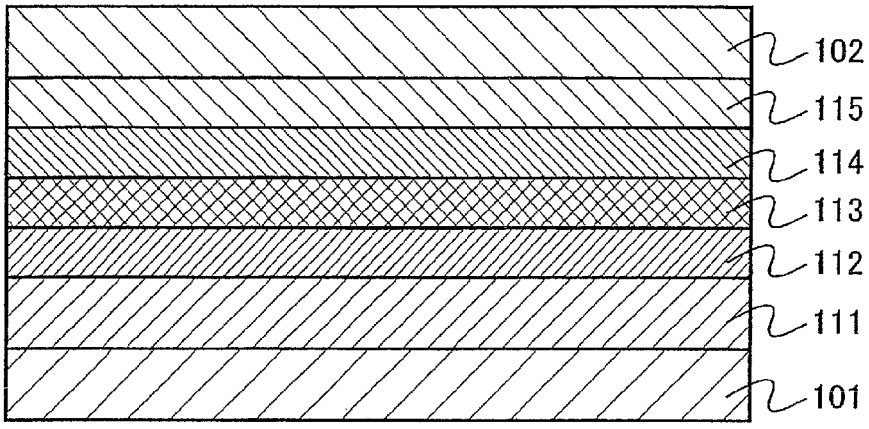


Fig.2

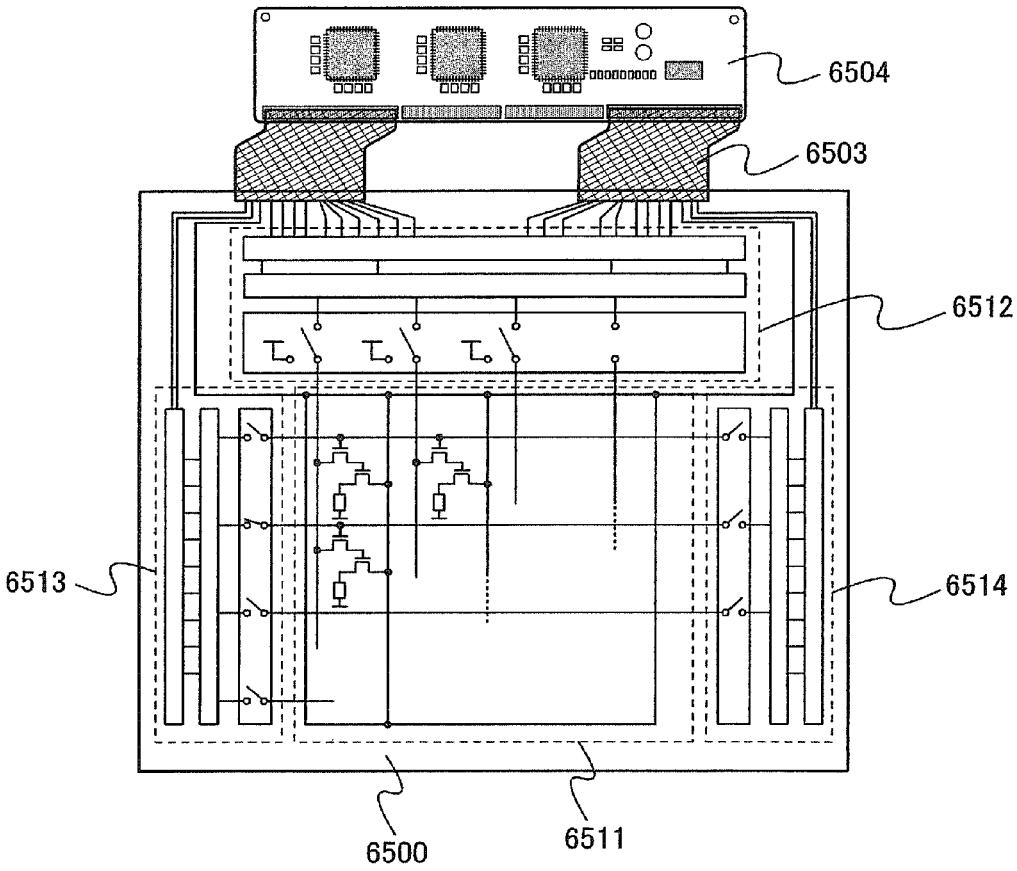


Fig.3

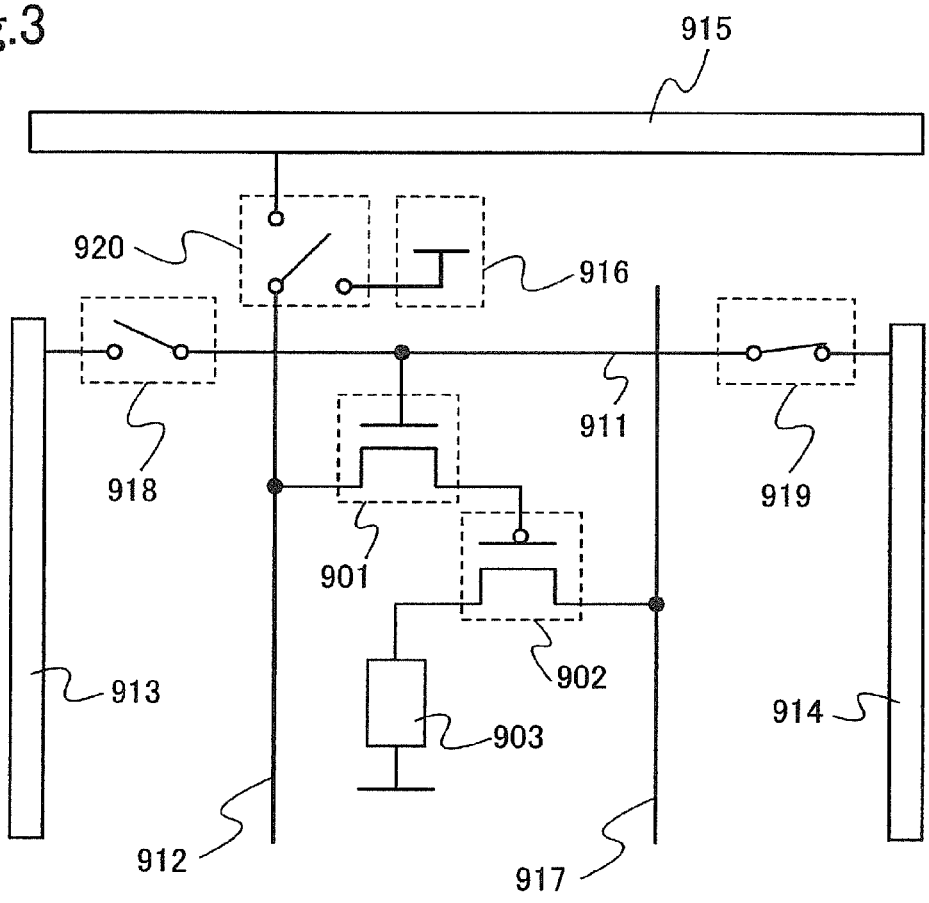
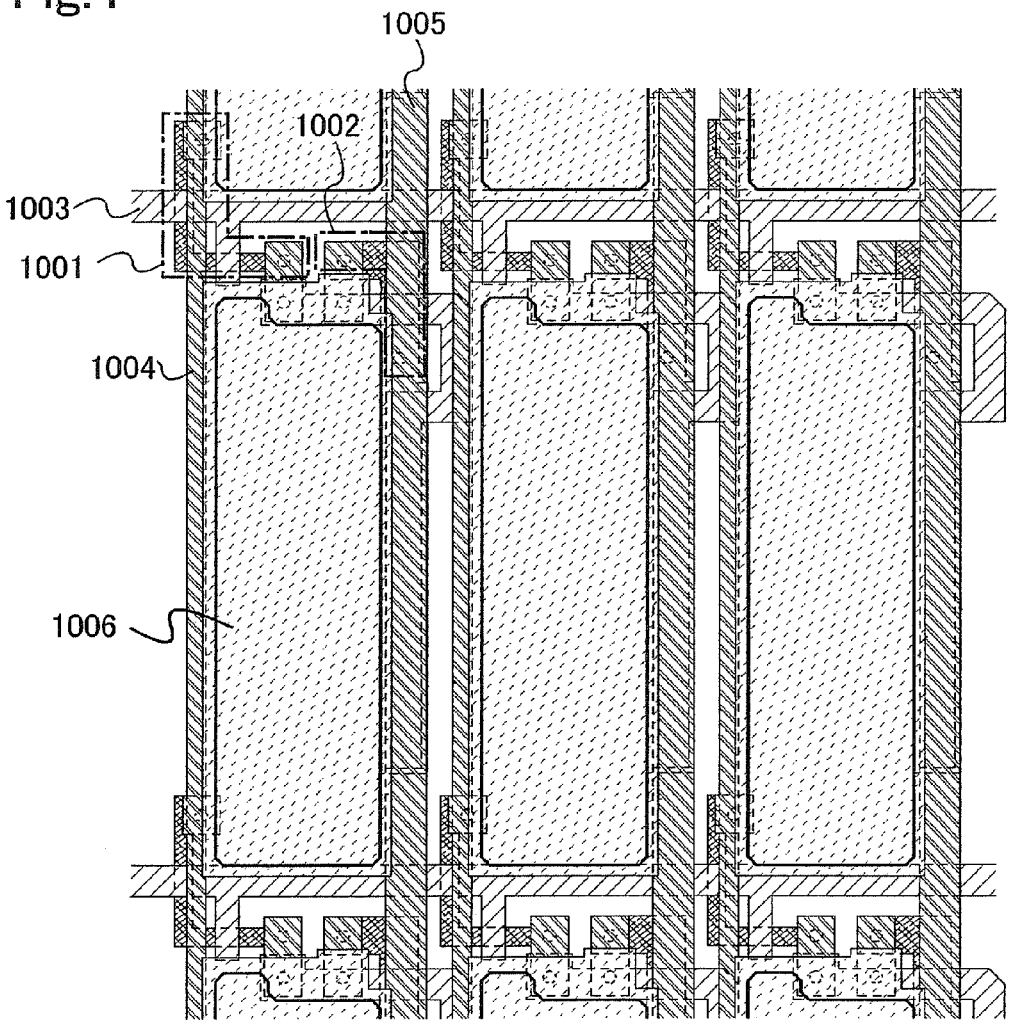


Fig.4



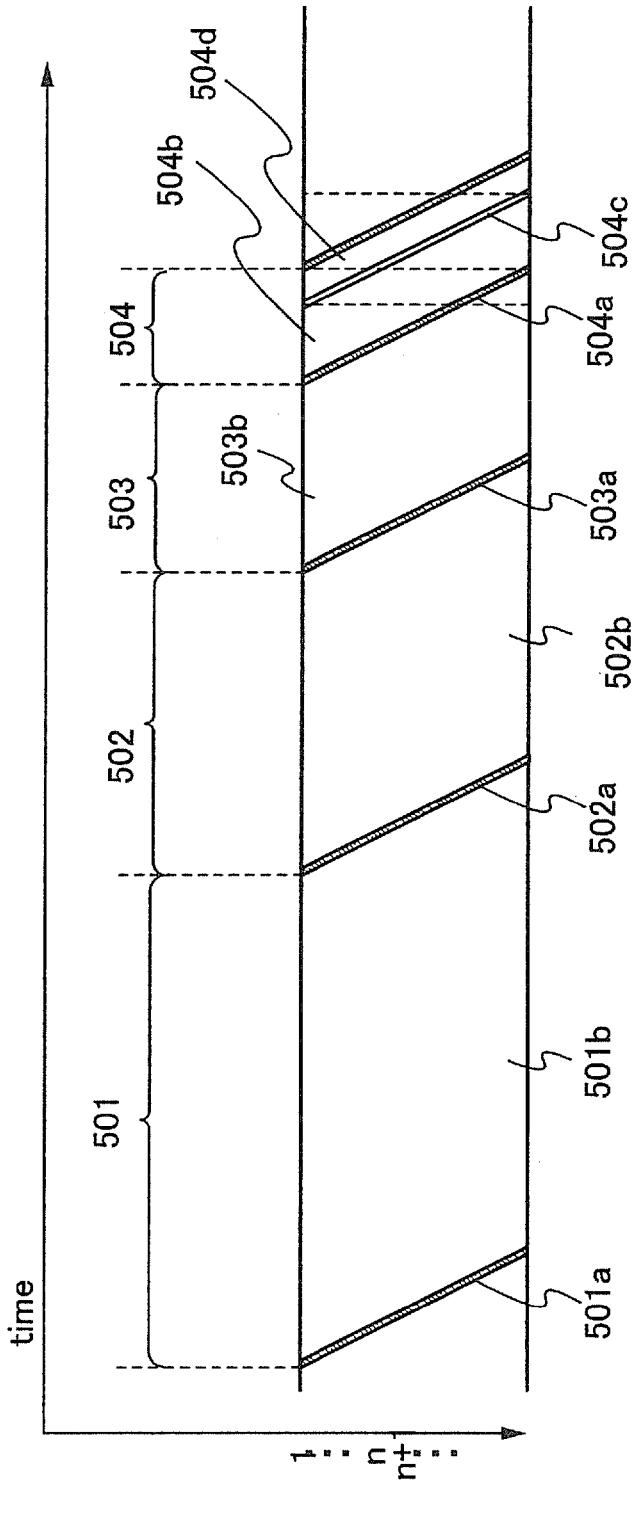

time
1
n
n+1
501
501a
501b
502
502a
502b
503
503a
503b
504
504a
504b
504c
504d

Fig.5

Fig.6A

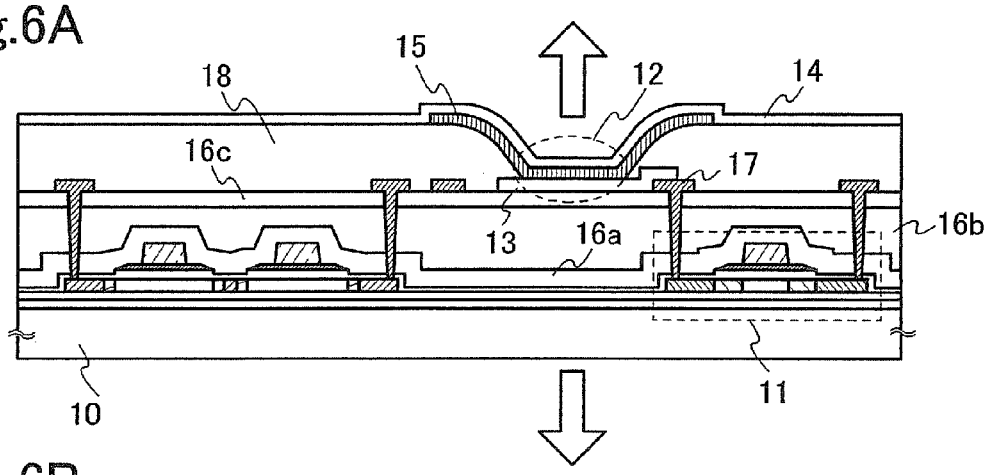


Fig.6B

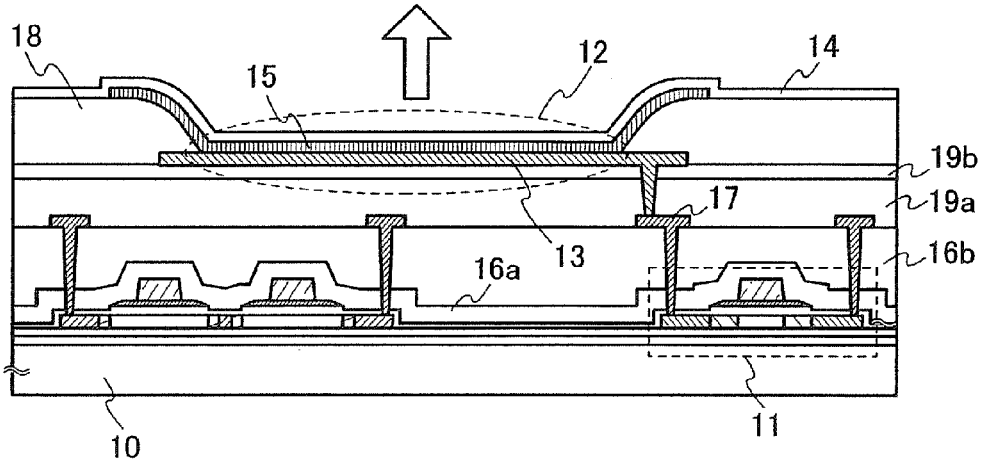
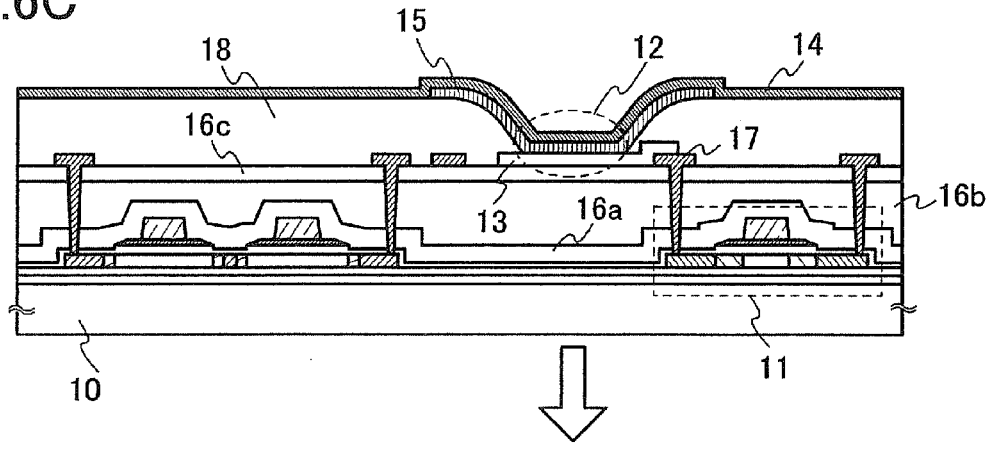


Fig.6C



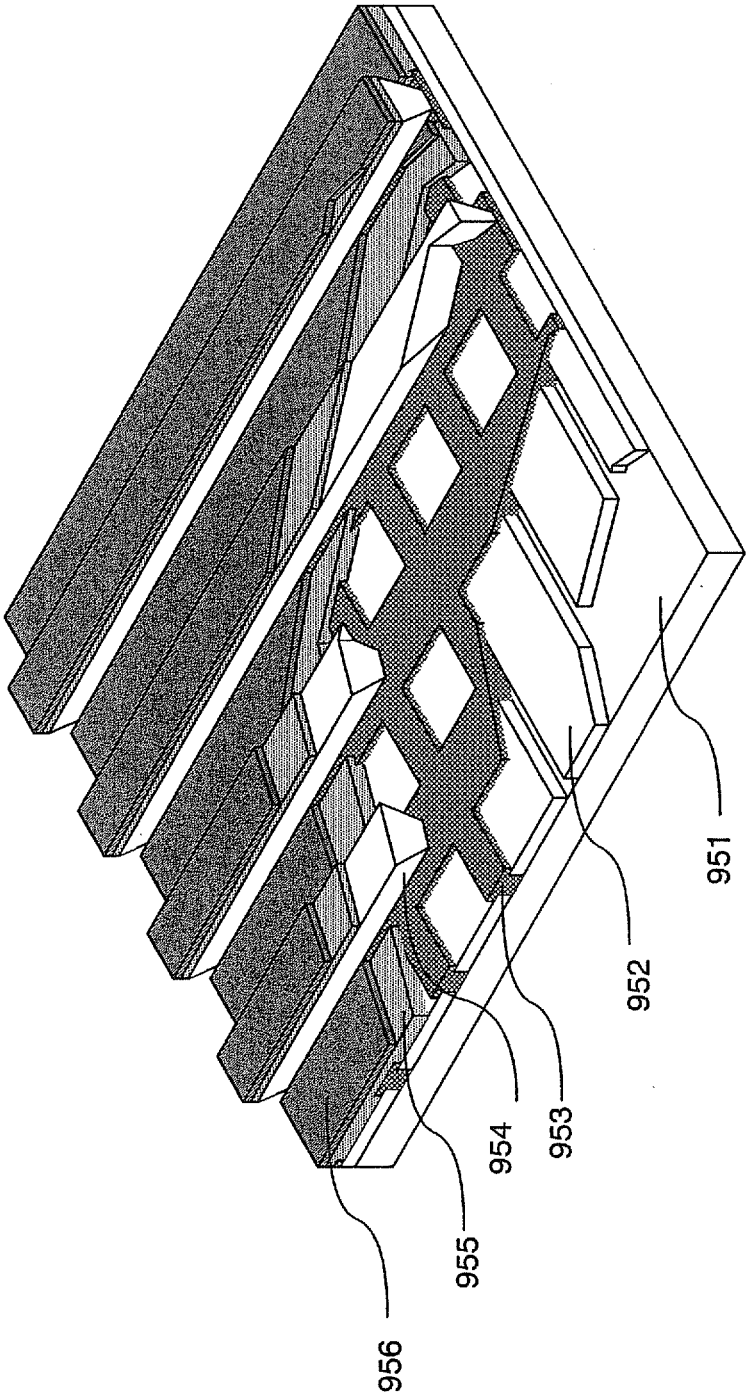


Fig.7

Fig.8A

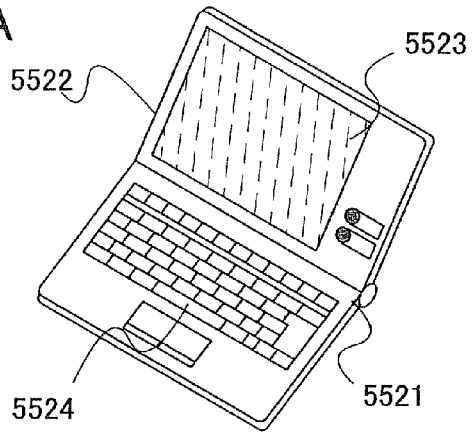


Fig.8B

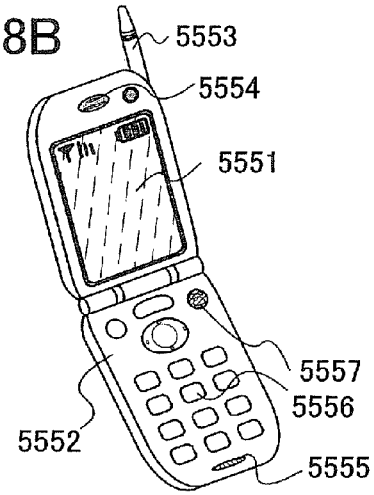


Fig.8C

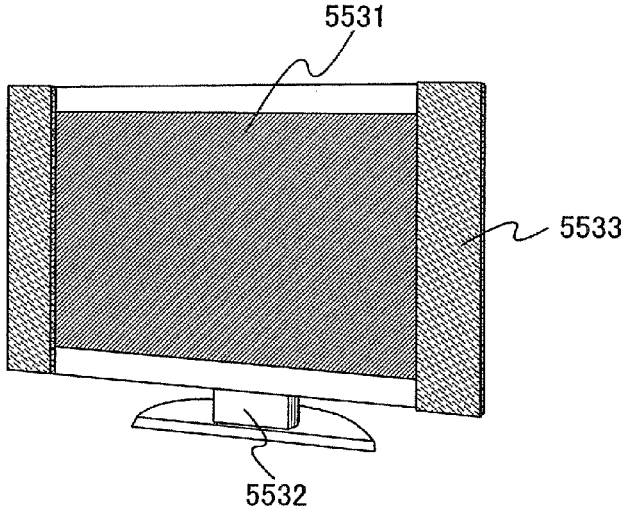


Fig.9

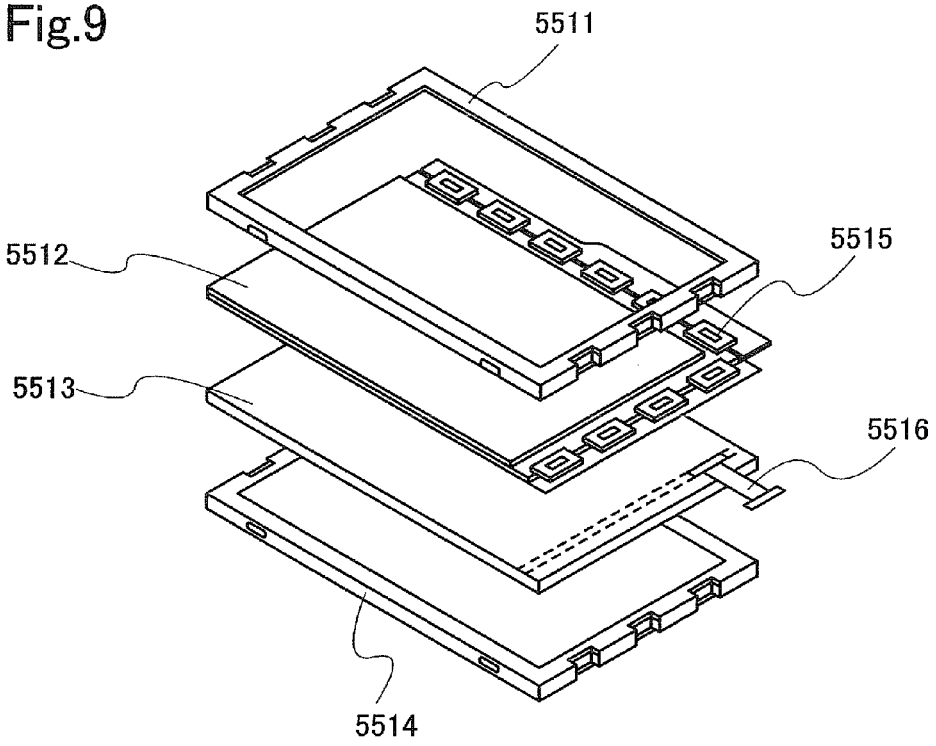


Fig.10

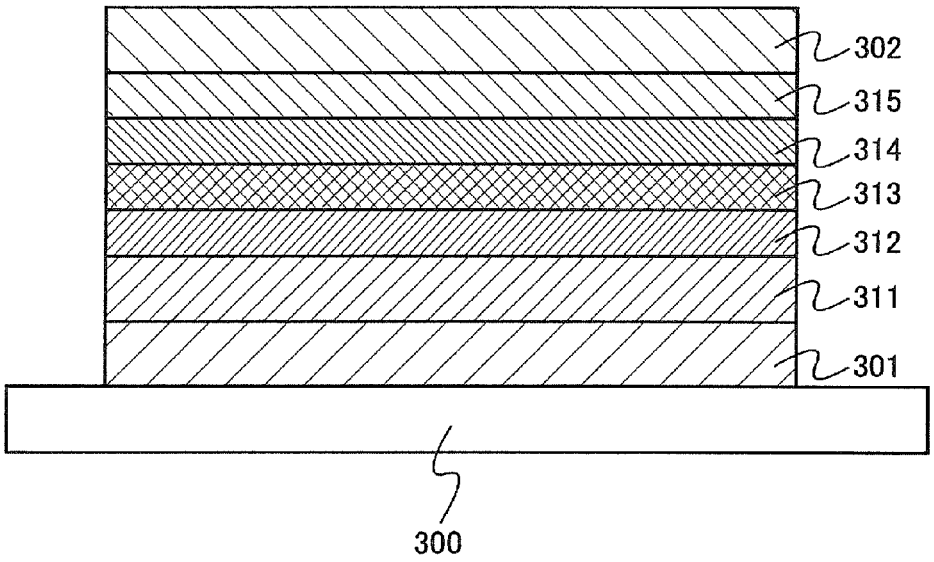


Fig.11

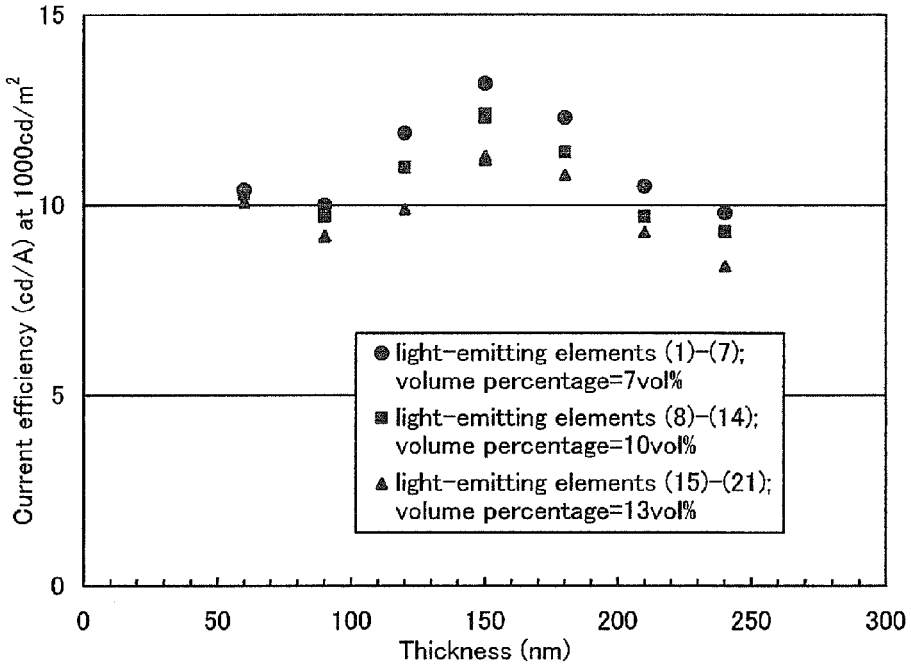

15
10
5
0
Current efficiency (cd/A) at 1000cd/m2
0
50
100
150
200
250
300
Thickness (nm)
light-emitting elements (1)-(7); volume percentage=7vol%
light-emitting elements (8)-(14); volume percentage=10vol%
light-emitting elements (15)-(21); volume percentage=13vol%

Fig.12

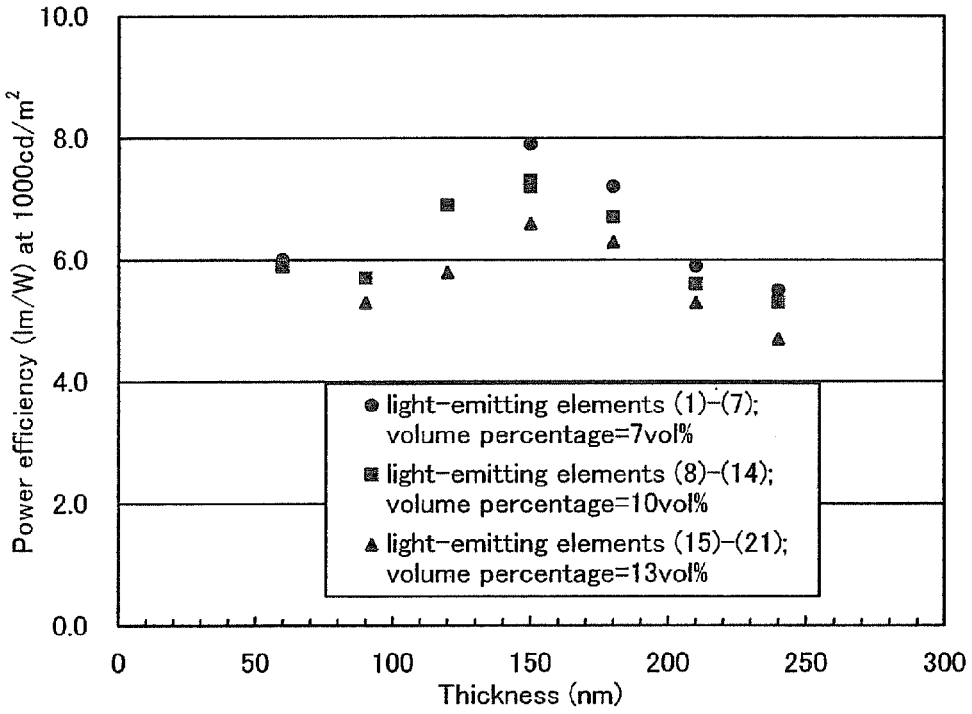

10.0
8.0
6.0
4.0
2.0
0.0
Power efficiency (lm/W) at 1000cd/m2
0
50
100
150
200
250
300
Thickness (nm)
light-emitting elements (1)-(7); volume percentage=7vol%
light-emitting elements (8)-(14); volume percentage=10vol%
light-emitting elements (15)-(21); volume percentage=13vol%

Fig.13

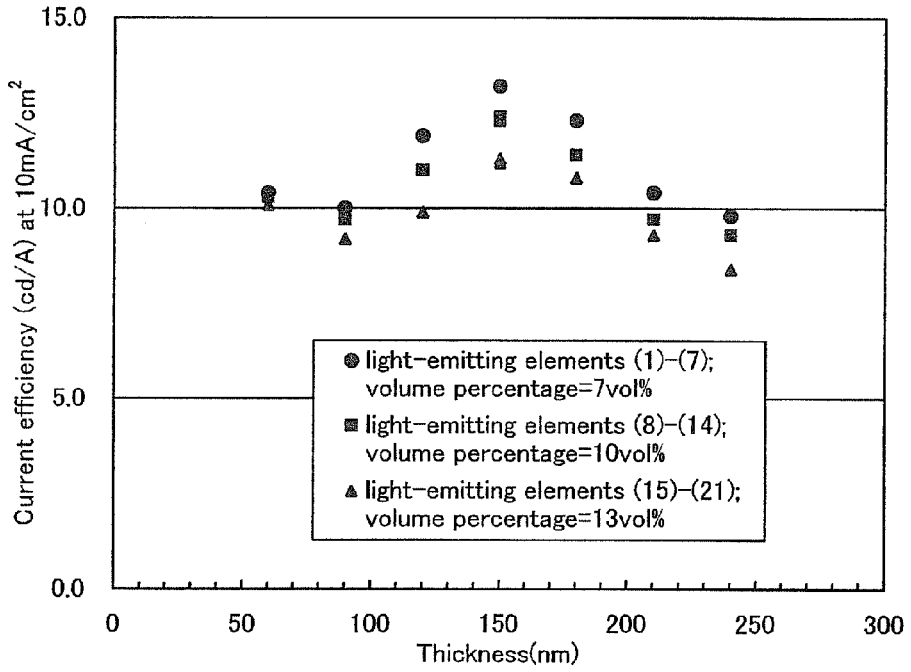

15.0
10.0
5.0
0.0
Current efficiency (cd/A) at 10mA/cm2
0
50
100
150
200
250
300
Thickness(nm)
light-emitting elements (1)-(7); volume percentage=7vol%
light-emitting elements (8)-(14); volume percentage=10vol%
light-emitting elements (15)-(21); volume percentage=13vol%

Fig.14

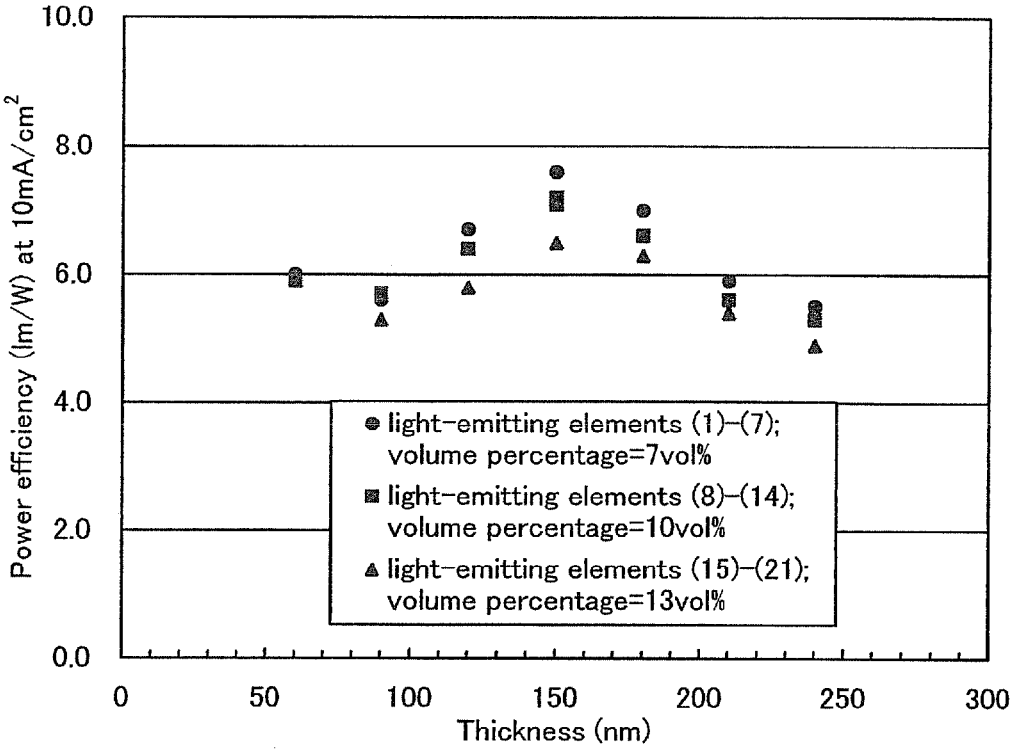

10.0
8.0
6.0
4.0
2.0
0.0
Power efficiency (lm/W) at 10mA/cm2
0
50
100
150
200
250
300
Thickness (nm)
light-emitting elements (1)-(7); volume percentage=7vol%
light-emitting elements (8)-(14); volume percentage=10vol%
light-emitting elements (15)-(21); volume percentage=13vol%

Fig.15A

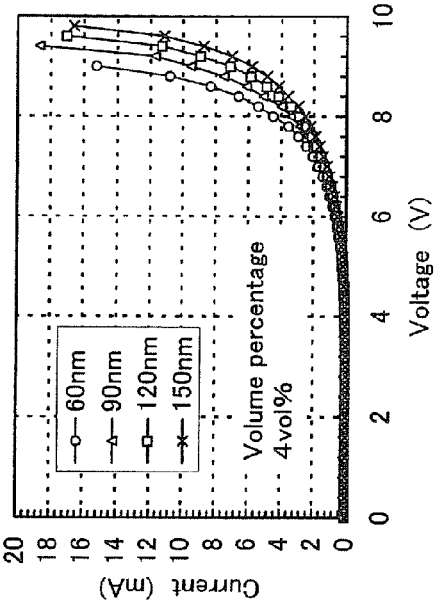


Fig.15B

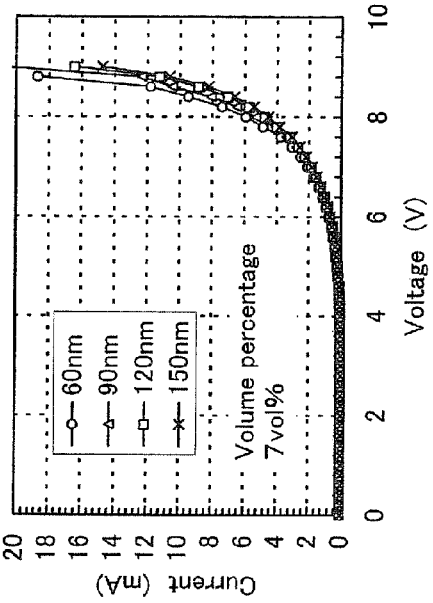


Fig.15C

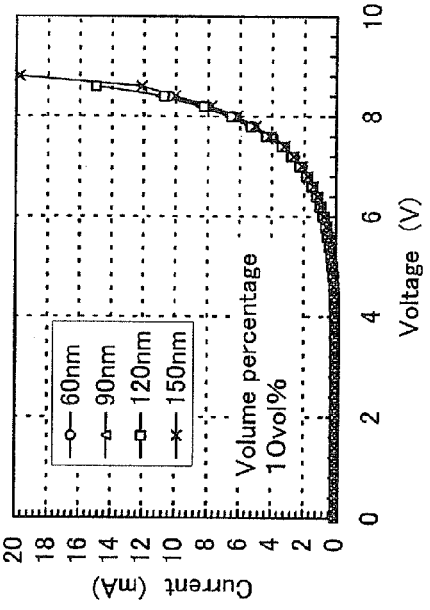


Fig.15D

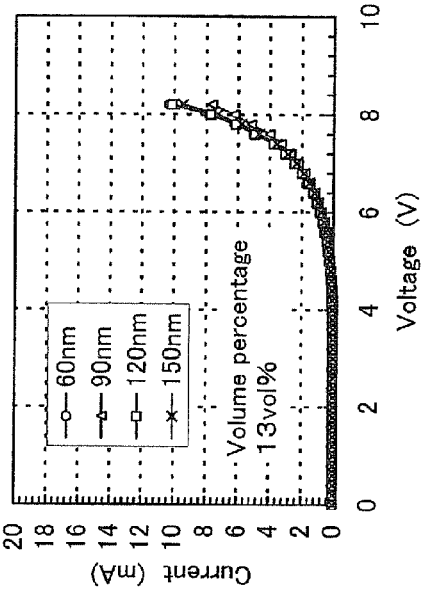


Fig.16

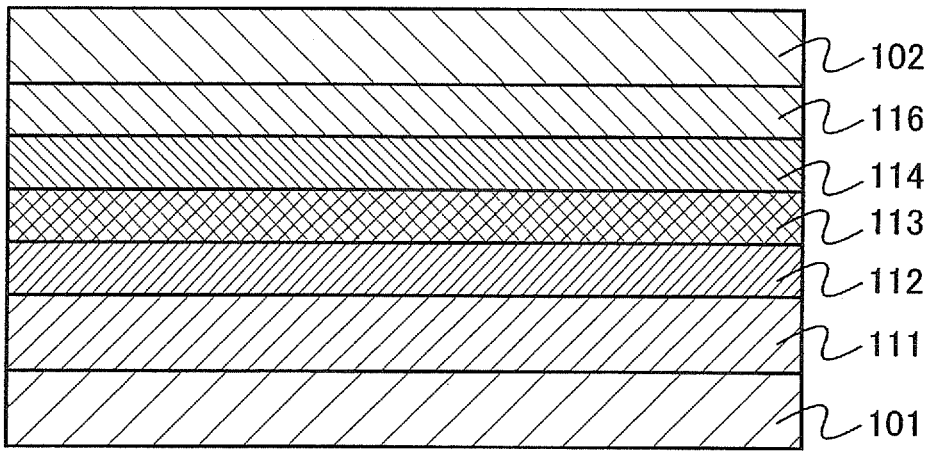
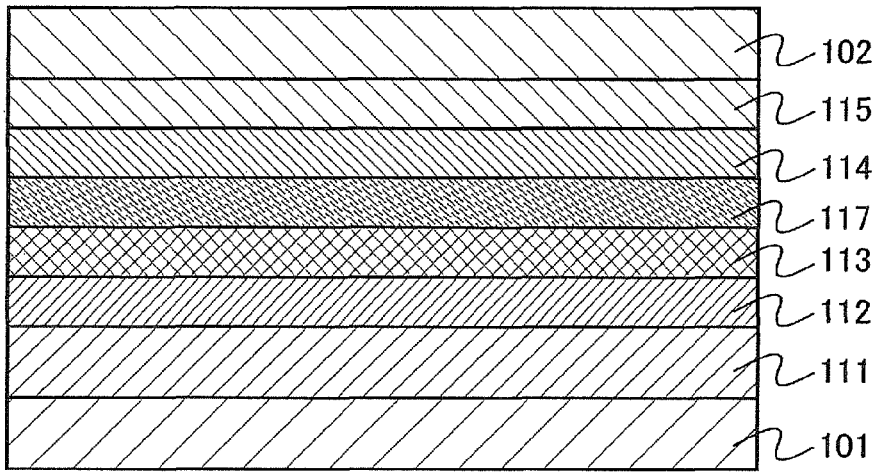


Fig.17



LIGHT-EMITTING ELEMENT, LIGHT-EMITTING DEVICE, AND ELECTRONIC DEVICE

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to light-emitting elements which emit light by current excitation, and light-emitting devices and electronic devices using the same.

2. Description of the Related Art

In EL displays which have been commercialized recently, images are displayed by changing and combining luminance, emission time or the like of red (R), green (G) and blue (B) luminescences. R, G and B luminescences can each be obtained by driving a light-emitting element in which a light-emitting layer is formed between a pair of electrodes. In such light-emitting elements, at least one of the electrodes is formed of a transparent conductive film such as ITO (indium tin oxide) so that visible light can pass therethrough.

In such light-emitting elements, when a distance between a light-emitting layer and an electrode through which light passes is not suitable (in other words, an optical path length is not controlled suitably), colors are changed strangely or an extraction efficiency of luminescence decreases. In order to solve such problems, a technique shown in Reference 1 has been proposed, for example (Reference 1: Japanese Patent Application Laid-Open No. 2001-102175).

Forming a metal doping layer to be in contact with a cathode as described in Reference 1 is thought to be effective. However, a problem remains with the technique as described in Reference 1 in that a distance between a light-emitting layer and an anode cannot be adjusted. In addition, a metal such as Mg or Li as described in Reference 1 can be a cause of reduction of a light-transmitting property.

SUMMARY OF THE INVENTION

It is an object of the present invention to provide a light-emitting element, a light-emitting device and an electronic device in which an optical path length through which generated light goes can be changed easily.

One feature of the present invention is a light-emitting element including a light-emitting layer between a first electrode and a second electrode, and a mixed layer in contact with the first electrode. The mixed layer includes a hole transporting substance and a metal oxide showing an electron accepting property to the hole transporting substance. A total film thickness of layers formed between the light-emitting layer and the first electrode is preferably in a range of 50 nm to 300 nm, and thus, the mixed layer is preferably formed to have a thickness of 10 nm to 250 nm (more preferably, 120 nm to 180 nm). By forming the mixed layer to have such a thickness, the light can be extracted to outside of the light-emitting element efficiently, especially when a light-emitting element for green emits light. Further, in the mixed layer, the metal oxide is preferably included at a percentage of 3 vol % to 24 vol % of the volume of the mixed layer, more preferably, a percentage of 7 vol % to 16 vol %, and most preferably, a percentage of 8 vol % to 12 vol %. Accordingly, a light-emitting element can operate more efficiently, and a light-emitting element with a small variation in driving voltage which is dependent on the thickness of the mixed layer, can be manufactured.

As the metal oxide, molybdenum oxide, vanadium oxide, ruthenium oxide, rhenium oxide or the like can be used, and of these oxides, molybdenum oxide is preferably used.

Molybdenum oxide itself has low hygroscopicity. When molybdenum oxide is heated in a vacuum, it does not produce moisture; thus a light-emitting element with very little degradation caused by moisture can be manufactured. Moreover, molybdenum oxide can be easily stored and handled; therefore, it is a suitable material for mass production. In addition, molybdenum trioxide is preferred as a metal oxide, since it has superior deposition stability. As a hole transporting substance, 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl, 4,4'-bis[N-(3-methylphenyl)-N-phenylamino]biphenyl, 1,3,5-tris[N,N-di(m-tolyl)amino]benzene, 4,4',4"-tris(N-carbazolyl)triphenylamine, 4,4'-bis{N-[4-(N,N-di-m-tolylamino)phenyl]-N-phenylamino}biphenyl or the like can be used.

By implementing the present invention, a light-emitting element can be obtained, which has a small variation of driving voltage which is dependent on a thickness of layers formed between an electrode serving as an anode and a light-emitting layer, and in which a length of an optical path can be easily changed. Further, a light-emitting device and an electronic device which can operate with low power consumption can be obtained by incorporating such a light-emitting element. Moreover, by implementing the present invention, reduction of extraction efficiency caused by a substance included in a layer provided so as to adjust an optical path length is small, and an excellent light-emitting element, and a light-emitting device and an electronic device which can operate with low power consumption can be obtained by incorporating the light-emitting element.

Moreover, in full-color display devices, in order to obtain white light emission by luminescences of three primary colors, blue, green and red, when luminescences of the three primary colors, blue, green and red are emitted at vertexes of NTSC (National Television Standards Committee), it is necessary to mix luminescence of each color with a ratio of approximately 1:6:3 (=blue:green:red). In other words, a lot of power is consumed, because green emission is needed at a maximum luminance. Thus, by implementing the present invention, power consumption of full-color display devices can be reduced by reducing power consumption of a light-emitting element for green.

BRIEF DESCRIPTION OF DRAWINGS

In the accompanying drawings:

FIG. **1** shows one mode of a light-emitting element according to an aspect of the present invention;

FIG. **2** shows one mode of a light-emitting device according to an aspect of the present invention;

FIG. **3** shows one mode of a circuit for driving a pixel formed in a light-emitting device according to an aspect of the present invention;

FIG. **4** shows one mode of a pixel portion included in a light-emitting device according to an aspect of the present invention;

FIG. **5** is a flame diagram describing a method for driving a pixel included in a light-emitting device according to an aspect of the present invention;

FIGS. **6**A to **6**C each show one mode of a cross section of a light-emitting device according to an aspect of the present invention;

FIG. **7** shows one mode of a light-emitting device according to an aspect of the present invention;

FIGS. **8**A to **8**C each show one mode of an electronic device to which the present invention is applied;

FIG. **9** shows a lighting device to which the present invention is applied;

FIG. **10** shows one example of a light-emitting element according to an aspect of the present invention;

FIG. **11** is a graph showing variation of current efficiency with respect to a thickness of a mixed layer (first layer **311**);

FIG. **12** is a graph showing variation of power efficiency with respect to a thickness of a mixed layer (first layer **311**);

FIG. **13** is a graph showing variation of current efficiency with respect to a thickness of a mixed layer (first layer **311**);

FIG. **14** is a graph showing variation of power efficiency with respect to a thickness of a mixed layer (first layer **311**);

FIGS. **15**A to **15**D are graphs showing current-voltage characteristics of light-emitting elements manufactured in Examples 1 and 2;

FIG. **16** shows one mode of an a light-emitting element according to an aspect of the present invention; and

FIG. **17** shows one mode of an a light-emitting element according to an aspect of the present invention.

DETAILED DESCRIPTION OF THE INVENTION

Hereinafter, the embodiment modes of the present invention will be described. The present invention is not limited to the following description, and it is easily understood by those skilled in the art that modes and details herein disclosed can be modified in various ways without departing from the spirit and the scope of the present invention. It should be noted that the present invention should not be interpreted as being limited to the description of the embodiment modes to be given below.

Embodiment Mode 1

One mode of a light-emitting element of the present invention will be described with reference to FIG. **1**.

In FIG. **1**, a light-emitting element having a light-emitting layer **113** between a first electrode **101** and a second electrode **102** is shown. In the light-emitting element shown in FIG. **1**, a mixed layer **111** is provided between the light-emitting layer **113** and the first electrode **101**. In addition, a hole transporting layer **112** is provided between the light-emitting layer **113** and the mixed layer **111**, and an electron transporting layer **114** and an electron injecting layer **115** are provided between the light-emitting layer **113** and the second electrode **102**. In such a light-emitting element, when a voltage is applied between the first electrode **101** and the second electrode **102** so that a potential of the first electrode **101** is higher than a potential of the second electrode **102**, holes are injected from the first electrode **101** side to the light-emitting layer **113**, and electrons are injected from the second electrode **102** side to the light-emitting layer **113**. In other words, the first electrode **101** has a function of an anode and the second electrode **102** has a function of a cathode. Subsequently, holes and electrons injected to the light-emitting layer **113** are recombined. A light-emitting substance is included in the light-emitting layer **113**, and the light-emitting substance moves into an excited state due to excitation energy generated by the recombination. The light-emitting substance in the excited state emits light upon returning to a ground state.

The first electrode **101**, the second electrode **102**, and each of the layers provided therebetween are described in detail below.

There is no particular limitation on a substance for forming the first electrode **101**; however, in addition to a substance having a high work function, such as indium tin oxide, indium tin oxide containing silicon oxide, indium oxide containing 2 to 20 wt % zinc oxide, gold (Au), platinum (Pt), nickel (Ni), tungsten (W), chromium (Cr), molybdenum (Mo), iron (Fe), cobalt (Co), copper (Cu), palladium (Pd), or tantalum nitride, a substance having a low work function such as aluminum or magnesium can also be used. This is because holes are generated from the mixed layer **111** when a voltage is applied between the electrodes in the light-emitting element of the present invention.

As a substance forming the second electrode **102**, a substance having a low work function such as aluminum or magnesium is preferable; however, when an electron-generating layer is provided between the second electrode **102** and the light-emitting layer **113**, a substance having a high work function, such as indium tin oxide, indium tin oxide containing silicon oxide, indium oxide containing 2 to 20 wt % zinc oxide, gold (Au), platinum (Pt), nickel (Ni), tungsten (W), chromium (Cr), molybdenum (Mo), iron (Fe), cobalt (Co), copper (Cu), palladium (Pd), or tantalum nitride, can also be used. Accordingly, a substance which is suitable as a substance for forming the second electrode **102** may be selected as appropriate, depending on a property of a layer or layers to be provided between the second electrode **102** and the light-emitting layer **113**.

Note that the first electrode **101** and the second electrode **102** are preferably formed so that either one or both of the electrodes can transmit light that is emitted.

The mixed layer **111** is a layer including a hole transporting substance and a metal oxide. There is no limitation on a hole transporting substance; however, it is preferable that the hole transporting substance has a hole mobility of 1×10^{-6} cm^2/Vs or higher, (more preferably 1×10^{-6} to 1×10^{0} cm^2/Vs). Holes injected from a metal oxide can be transported efficiently by using a hole transporting material having a hole mobility of 1×10^{-6} cm^2/Vs or higher. Here, "hole transporting substance" refers to a substance having a higher hole mobility than electron mobility, and preferably, a substance for which a value of a ratio of hole mobility to electron mobility (=hole mobility/electron mobility) is larger than 100. As examples of the hole transporting substance, 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (abbreviated as NPB), 4,4'-bis[N-(3-methylphenyl)-N-phenylamino]biphenyl (abbreviated as TPD), 1,3,5-tris[N,N-di(m-tolyl)amino]benzene (abbreviated as m-MTDAB), 4,4',4"-tris(N-carbazolyl)triphenylamine (abbreviated as TCTA), 4,4'-bis{N-[4-(N,N-di-m-tolylamino)phenyl]-N-phenylamino}biphenyl (abbreviated as DNTPD) and the like can be given. Further, as the metal oxide, a substance showing an electron accepting property to the hole transporting substance is preferable. As examples of a metal oxide, molybdenum oxide, vanadium oxide, ruthenium oxide, rhenium oxide and the like can be given. Further, metal oxides such as titanium oxide, chromium oxide, zirconium oxide, hafnium oxide, tantalum oxide, tungsten oxide, and silver oxide can also be used. By combining a metal oxide and a hole transporting substance in this manner, a light-emitting element in which increase of driving voltage dependent on a film thickness of the mixed layer **111** is extremely small, and in which a distance from the light-emitting layer **113** to the first electrode **101** can be freely changed, can be obtained. Moreover, metal oxides such as those cited here are superior in light-transmitting properties to metals such as Li and Mg. Thus, light can be emitted to the outside of the light-emitting element easily and decrease in extraction efficiency can be prevented. Such a metal oxide is preferably included in the mixed layer **111** such that a mass ratio of the metal oxide to the hole transporting substance is 0.1 to 1 (=metal oxide/hole transporting substance), or a molar ratio is 0.4 to 4 (=metal oxide/hole transporting material), or a volume percentage of the metal oxide to the mixed layer **111** (mixing ratio) is 3 to 24 vol %, more preferably 7 to 16 vol %, and most preferably 8 to 12 vol %. A total thickness of layers formed between the light-emitting layer **113** and the first electrode **101** is prefer-

ably 50 to 300 nm, thus, the mixed layer **111** is preferably formed to have a thickness of 10 to 250 nm (more preferably 120 to 180 nm).

The hole transporting layer **112** has a layer having a function of transporting holes. The hole transporting layer **112** has a function of transporting holes from the mixed layer **111** to the light-emitting layer **113** in the light-emitting element of this embodiment mode. By providing the hole transporting layer **112**, a distance between the mixed layer **111** and the light-emitting layer **113** can be made larger. As a result, light can be prevented from being quenched due to the metal included in the mixed layer **111**. The hole transporting layer **112** is preferably formed of a hole transporting substance, particularly, a hole transporting substance or a bipolar substance each having a hole mobility of 1×10^{-6} cm^2/Vs or more (more preferably, 1×10^{-6} to 1×100 cm^2/Vs). The following can be given as specific examples of a hole transporting substance which can be used for forming the hole transporting layer **112**: 4,4'-bis[N-(1-naphthyl)-N-phenylamino]biphenyl (abbreviated as NPB); 4,4'-bis[N-(3-methylphenyl)-N-phenylamino]biphenyl (abbreviated as TPD); 1,3,5-tris[N,N-di(m-tolyl)amino]benzene (abbreviated as m-MTDAB); 4,4',4"-tris(N-carbazolyl)triphenylamine (abbreviated as TCTA); and the like. "Bipolar substance" denotes a substance where when mobility of an electron and mobility of a hole are compared with each other, the value of the ratio of the mobility of one carrier to the mobility of the other carrier is 100 or less, preferably 10 or less. As the bipolar substance, 2,3-bis(4-diphenylaminophenyl)quinoxaline (abbreviated as TPAQn); 2,3-bis{4-[N-(1-naphthyl)-N-phenylamino]phenyl}-dibenzo[f,h]quinoxaline (abbreviated as NPADiBzQn); and the like can be given, for example. Among bipolar substances, one bipolar substance having hole and electron mobility of 1×10^{-6} cm^2/Vs or more (more preferably 1×10^{-6} cm^2/Vs to 1×10^{0} cm^2/Vs) is preferably used. It is noted that the hole transporting layer **112** preferably has a thickness of 5 to 50 nm. By employing such a thickness, increase of a driving voltage due to the thickness of the hole transporting layer **112** can be suppressed.

The light-emitting layer **113** is a layer including a light-emitting substance. Here, "light-emitting substance" denotes a substance which can emit light with excellent luminous efficiency and at a desired wavelength. The light-emitting layer **113** may be a layer made of only a light-emitting substance. However, when a concentration quenching occurs, the light-emitting layer **113** is preferably a layer in which a light-emitting substance is mixed so as to be dispersed in a layer made of a substance having an energy gap larger than that of the light-emitting substance. By including a light-emitting substance in the light-emitting layer **113** such that it is dispersed, light emission can be prevented from being quenched due to the concentration. Here, "energy gap" denotes an energy gap between a LUMO (Lowest Unoccupied Molecular Orbital) level and a HOMO (Highest Occupied Molecular Orbital) level.

There is no particular limitation on the light-emitting substance, and as long as a substance can emit light with excellent luminous efficiency and at a desired emission wavelength, the substance can be used. In order to obtain red light emission, for example, the following substances exhibiting light emission whose peak in the spectrum is in a 600 nm to 680 nm wavelength range can be used as the light-emitting substance: 4-dicyanomethylene-2-isopropyl-6-[2-(1,1,7,7-tetramethyl-9-julolidyl)ethenyl]-4H-pyran (abbreviated as DCJTI); 4-dicyanomethylene-2-methyl-6-[2-(1,1,7,7-tetramethyl-9-julolidyl)ethenyl]-4H-pyran (abbreviated as DCJT); 4-dicyanomethylene-2-tert-butyl-6-[2-(1,1,7,7-tetramethyl-9-julolidyl)ethenyl]-4H-pyran (abbreviated as DCJTB); periflanthene; 2,5-dicyano-1,4-bis[2-(10-methoxy-1,1,7,7-tetramethyl-9-julolidyl)ethenyl]benzene; or the like. In order to obtain green light emission, substances exhibiting light emission whose peak in the spectrum is in a 500 nm to 550 nm wavelength range, such as N,N'-dimethylquinacridone (abbreviated as DMQd), coumarin 6, coumarin 545T, or tris(8-quinolinolato)aluminum (abbreviated as Alq_3), can be used as the light-emitting substance. In order to obtain blue light emission, the following substances exhibiting light emission whose peak in the spectrum is in a 420 nm to 500 nm wavelength range, can be used as a light-emitting substance: 9,10-bis(2-naphthyl)-tert-butylanthracene (abbreviated as t-BuDNA); 9,9'-bianthryl; 9,10-diphenylanthracene (abbreviated as DPA); 9,10-bis(2-naphthyl)anthracene (abbreviated as DNA); bis(2-methyl-8-quinolinolato)-4-phenylphenolato-gallium (abbreviated as BGaq); bis(2-methyl-8-quinolinolato)-4-phenylphenolato-aluminum (abbreviated as BAlq); or the like. As mentioned above, as well as such substances which emit fluorescence, the following substance which emits phosphorescence can also be used as the light-emitting substance: bis[2-(3,5-bis(trifluoromethyl)phenyl)pyridinato-N,$C^{2'}$]iridium(III)picolinate (abbreviated as $Ir(CF_3ppy)_2$(pic)); bis[2-(4,6-difluorophenyl) pyridinato-N, $C^{2'}$]iridium (III)acetylacetonate (abbreviated as FIr(acac)); bis[2-(4,6-difluorophenyl)pyridinato-N,$C^{2'}$]iridium(III)picolinate (abbreviated as FIr(pic)); tris(2-phenylpyridinato-N,$C^{2'}$)iridium (abbreviated as $Ir(ppy)_3$); or the like.

In addition, there is no particular limitation on a substance which is included in the light-emitting layer **113** along with the light-emitting substance and which is used to disperse the light-emitting substance. Such a substance may be selected appropriately in terms of an energy gap or the like of a substance which is used as a light-emitting substance. For example, a metal complex such as bis[2-(2-hydroxyphenyl) pyridinato]zinc (abbreviated as $Znpp_2$) or bis[2-(2-hydroxyphenyl)benzoxazolato]zinc (abbreviated as ZnBOX), in addition to an anthracene derivative such as 9,10-di(2-naphthyl)-2-tert-butylanthracene (abbreviated as t-BuDNA); a carbazole derivative such as 4,4'-bis(N-carbazolyl)biphenyl (abbreviated as CBP); a quinoxaline derivative such as 2,3-bis(4-diphenylaminophenyl)quinoxaline (abbreviated as TPAQn) or 2,3-bis{4-[N-(1-naphthyl)-N-phenylamino]phenyl}-dibenzo[f,h]quinoxaline (abbreviated as NPADiBzQn) can be used along with a light-emitting substance.

The electron transporting layer **114** is a layer having a function of transporting electrons and has a function of transporting electrons from the second electrode **102** side to the light-emitting layer **113** in a light-emitting element of this embodiment mode. By providing the electron transporting layer **114**, a distance between the second electrode **102** and the light-emitting layer **113** can be made larger. Consequently, light emission can be prevented from being quenched due to metal included in the second electrode **102**. The electron transporting layer is preferably formed of an electron transporting substance and in particular, is preferably formed of an electron transporting substance or a bipolar substance each having electron mobility of 1×10^{-6} cm^2/Vs or more (preferably, 1×10^{-6} cm^2/VS to 1×10^{0} cm^2/Vs). Here, "electron transporting substance" denotes a substance having electron mobility higher than hole mobility, and preferably, a substance having a value of a ratio of the electron mobility to the hole mobility (=electron mobility/hole mobility) of more than 100. The following can be given as specific examples of an electron transporting substance: 2-(4-biphenylyl)-5-(4-tert-buthylphenyl)-1,3,4-oxadiazole (abbreviated as PBD); 1,3-bis[5-(p-tert-buthylphenyl)-1,3,4-oxadiazole-2-yl]ben-

zene (abbreviated as OXD-7); 3-(4-tert-butylphenyl)-4-phenyl-5-(4-biphenylyl)-1,2,4-triazole (abbreviated as TAZ); 3-(4-tert-butylphenyl)-4-(4-ethylphenyl)-5-(4-biphenylyl)-1,2,4-triazole (abbreviated as p-EtTAZ); bathophenanthroline (abbreviated as BPhen); bathocuproin (abbreviated as BCP); 4,4-bis(5-methylbenzoxazolyl-2-yl)stilbene (abbreviated as BzOs); and the like, in addition to a metal complex such as tris(8-quinolinolato)aluminum (abbreviated as: A^1q_3); tris(4-methyl-8-quinolinolato)aluminum (abbreviated as: $Almq_3$); bis(10-hydroxybenzo[h]-quinolinato)berylium (abbreviated as: $BeBq_2$); bis(2-methyl-8-quinolinolato)(4-phenylphenolato)aluminum (abbreviated as: BAlq); bis[2(2-hydroxyphenyl)benzoxazolato]zinc (abbreviated as: $Zn(BOX)_2$); and bis[2(2-hydroxyphenyl)benzothiazolato]zinc (abbreviated as: $Zn(BTZ)_2$). It is to be noted that the bipolar substance has been described above. The electron transporting layer **114** and the hole transporting layer **112** may be formed of the same bipolar substance. Note that the electron transporting layer **114** preferably has a thickness of 5 to 30 nm. By employing such a thickness, increase of driving voltage due to the thickness of the electron transporting layer **114** can be suppressed.

The electron injecting layer **115** is a layer having a function of assisting electrons to be injected from the second electrode **102** to the electron transporting layer **114**. By providing the electron injecting layer **115**, a difference in electron affinity between the second electrode **102** and the electron transporting layer **114** is relieved; thus, electrons are easily injected. The electron injecting layer **115** is preferably made of a substance of which electron affinity is higher than that of a substance for forming the electron transporting layer **114** and is lower than that of a substance for forming the second electrode **102**. Alternatively, the electron injecting layer **115** is preferably made of a substance whose energy band curves by being provided as a thin film of about 1 nm to 2 nm thick between the electron transporting layer **114** and the second electrode **102**. The following can be given as specific examples of a substance which can be used to form the electron injecting layer **115**: inorganic substances such as alkali metal such as lithium (Li); alkaline earth metal such as magnesium (Mg); fluoride of alkali metal such as cesium fluoride (CsF); fluoride of alkaline earth metal such as calcium fluoride (CaF_2); oxide of alkali metal such as lithium oxide (Li_2O), sodium oxide (Na_2O), or potassium oxide (K_2O); or oxide of alkaline earth metal such as calcium oxide (CaO) or magnesium oxide (MgO). These substances are preferable because an energy band thereof curves when they are provided as a thin film. In addition to such inorganic substances, an organic substance which can be used to form the electron transporting layer **114**, such as bathophenanthroline (abbreviated as BPhen); bathocuproin (abbreviated as BCP); 3-(4-tert-buthylphenyl)-4-(4-ethylphenyl)-5-(4-biphenylyl)-1,2,4-triazole (abbreviated as p-EtTAZ); or 3-(4-tert-buthylphenyl)-4-phenyl-5-(4-biphenylyl)-1,2,4-triazole (abbreviated as TAZ), can also be used as a substance for forming the electron injecting layer **115** by selecting a substance of which electron affinity is higher than that of a substance for forming the electron transporting layer **114** among these substances. In other words, the electron injecting layer **115** may be formed by selecting such a substance that electron affinity in the electron injecting layer **115** is higher than electron affinity in the electron transporting layer **114**. It is to be noted that the second electrode **102** is preferably made using a substance having a low work function such as aluminum in a case of providing the electron injecting layer **115**.

In the light-emitting element explained as above, each of the electron transporting substance and the hole transporting substance is preferably selected so that a ratio of mobility of one substance to mobility of the other substance is 1000 or less when mobility of an electron transporting substance used for forming the electron transporting layer **114** and mobility of the hole transporting substance included in the mixed layer **111**. Thus, recombination efficiency in the light-emitting layer can be increased by selecting each substance. In this embodiment mode, the light-emitting element having the hole transporting layer **112**, the electron transporting layer **114**, the electron injecting layer **115**, and the like, in addition to the mixed layer **111** and the light-emitting layer **113** is shown; however, a mode of the light-emitting element is not limited thereto. For example, as shown in FIG. **16**, a structure having an electron-generating layer **116** or the like instead of the electron injecting layer **115** may be employed. The electron-generating layer **116** is a layer for generating electrons, and can be formed by mixing at least one substance of an electron transporting substance and a bipolar substance, with a substance which shows an electron-donating property to these substances. Here, it is preferable to use a substance having electron mobility of 1×10^0 cm^2/Vs or more (more preferably, 1×10^{-6} to 1×10^0 cm^2/Vs), especially, among the electron transporting substances and the bipolar substances. As for the electron transporting substance and the bipolar substance, the above mentioned substances can be used. In addition, as for a substance which shows an electron-donating property, a substance among alkali metals or alkaline earth metals, specifically lithium (Li), calcium (Ca), sodium (Na), potassium (K), magnesium (Mg), or the like can be used. Moreover, alkali metal oxide, alkaline earth metal oxide, alkali metal nitride, alkaline earth metal nitride, alkali metal fluoride, or alkaline earth metal fluoride, specifically at least one substance selected from lithium oxide (Li_2O), calcium oxide (CaO), sodium oxide (Na_2O), potassium oxide (K_2O), magnesium oxide (MgO), lithium fluoride (LiF), cesium fluoride (CsF), calcium fluoride (CaF_2), or the like can also be used as the substance which shows an electron-donating property.

In addition, a hole blocking layer **117** may be provided between the light-emitting layer **113** and the electron transporting layer **114** as shown in FIG. **17**. By providing the hole blocking layer **117**, holes can be prevented from flowing to the second electrode **102** side after passing through the light-emitting layer **113**; thus, recombination efficiency of carriers can be increased. Moreover, excitation energy generated in the light-emitting layer **113** can be prevented from translating to other layers such as the electron transporting layer **114**. The hole blocking layer **117** can be formed by selecting a substance having higher ionization potential and higher excitation energy than a substance used to form the light-emitting layer **113**, especially, among substances which can be used to form the electron transporting layer **114** such as BAlq, OXD-7, TAZ, and BPhen. In other words, it is acceptable as long as the hole blocking layer **117** is formed by selecting a substance so that ionization potential in the hole blocking layer **117** is comparatively higher than that in the electron transporting layer **114**. In the same manner, a layer for blocking electrons from flowing to the first electrode **101** side after passing through the light-emitting layer **113** may also be provided between the light-emitting layer **113** and the hole transporting layer **112**.

It is to be noted that whether the electron injecting layer **115**, the electron transporting layer **114**, and the hole transporting layer **112** are to be provided or not may be appropriately decided by a practitioner of the present invention, and

these layers are not always necessary to be provided, for example, in a case where there is no malfunction such as quenching of light due to metal even when the hole transporting layer **112**, the electron transporting layer **114**, and the like are not provided, or a case where electrons are favorably injected from an electrode even when the electron injecting layer **115** is not provided.

As described above, by using a light-emitting element having the mixed layer **111** including a hole transporting substance and a metal oxide, it is easy that a distance between the first electrode **101** and the light-emitting layer **113** is adjusted so that light can be extracted efficiently or color purity of light extracted to the outside can be enhanced (in other words, an optical path length (optical length) through which emitted light goes).

The light-emitting element explained as above may be manufactured by a method for forming the second electrode **102** after sequentially stacking the mixed layer **111**, the hole transporting layer **112**, the light-emitting layer **113**, the electron transporting layer **114**, the electron injecting layer **115**, and the like on the first electrode **101**, or may be manufactured by a method for forming the first electrode **101** after sequentially stacking the electron injecting layer **115**, the electron transporting layer **114**, the light-emitting layer **113**, the hole transporting layer **112**, the mixed layer **111**, and the like on the second electrode **102**.

Embodiment Mode 2

In a light-emitting element of the present invention, an optical path length can be easily adjusted to extract light outside the light-emitting element efficiently. Thus, by using the light-emitting element described in Embodiment Mode 1 as a pixel, a light-emitting device which can conduct display operation with low power consumption can be obtained.

In this embodiment mode, a circuit configuration and a driving method of a light-emitting device having a display function are described with reference to FIGS. **2** to **6**.

FIG. **2** is a schematic top view of a light-emitting device to which the present invention is applied. In FIG. **2**, a pixel portion **6511**, a source signal line driving circuit **6512**, a writing gate signal line driving circuit **6513**, and an erasing gate signal line driving circuit **6514** are provided over a substrate **6500**. Each of the source signal line driving circuit **6512**, the writing gate signal line driving circuit **6513**, and the erasing gate signal line driving circuit **6514** is connected to FPCs (flexible printed circuits) **6503** that are external input terminals through a group of wirings. Further, each of the source signal line driving circuit **6512**, the writing gate signal line driving circuit **6513**, and the erasing gate signal line driving circuit **6514** receives signals such as a video signal, a clock signal, a start signal, and a reset signal from the FPCs **6503**. In addition, a printed wiring board (PWB) **6504** is attached to the FPCs **6503**. It is not always necessary to provide the driving circuit portion over the same substrate as the pixel portion **6511** as described above. For example, the driving circuit portion may be provided outside the substrate by using a TCP (Tape Carrier Package) etc., in which an IC chip is mounted over an FPC where a wiring pattern is formed.

In the pixel portion **6511**, a plurality of source signal lines extending in columns are arranged in rows. In addition, current-supply lines are arranged in rows, and a plurality of gate signal lines extending in rows are arranged in columns in the pixel portion **6511**. Further, a plurality of pairs of circuits each including a light-emitting element are arranged in the pixel portion **6511**.

FIG. **3** shows a circuit for operating one pixel. The circuit shown in FIG. **3** includes a first transistor **901**, a second transistor **902**, and a light-emitting element **903**.

Each of the first transistor **901** and the second transistor **902** is a three-terminal element including a gate electrode, a drain region, and a source region, and includes a channel region between the drain region and the source region. Here, since a source region and a drain region are switched with each other in accordance with a structure or operating conditions of a transistor, it is difficult to identify which one is the drain region or the source region. Therefore, in this embodiment mode, regions that serve as a source or a drain are referred to as a first electrode and a second electrode of the transistor, respectively.

A gate signal line **911** and a writing gate signal line driving circuit **913** are provided so as to be electrically connected or disconnected by a switch **918**. The gate signal line **911** and an erasing gate signal line driving circuit **914** are provided so as to be electrically connected or disconnected by a switch **919**. Further, a source signal line **912** is provided so as to be electrically connected to any of a source signal line driving circuit **915** and a power source **916** by a switch **920**. A gate of the first transistor **901** is electrically connected to the gate signal line **911**, a first electrode of the first transistor is electrically connected to the source signal line **912**, and a second electrode is electrically connected to a gate electrode of the second transistor **902**. A first electrode of the second transistor **902** is electrically connected to a current-supply line **917** and a second electrode is electrically connected to one electrode included in the light-emitting element **903**. It is to be noted that the switch **918** may be included in the writing gate signal line driving circuit **913**, the switch **919** may be included in the erasing gate signal line driving circuit **914**, and the switch **920** may be included in the source signal line driving circuit **915**.

In addition, arrangement of a transistor, a light-emitting element, and the like in a pixel portion is not particularly limited. For example, arrangement shown in a top view of FIG. **4** can be employed. In FIG. **4**, a first electrode of a first transistor **1001** is connected to a source signal line **1004** and a second electrode is connected to a gate electrode of a second transistor **1002**. Moreover, a first electrode of the second transistor **1002** is connected to a current-supply line **1005** and a second electrode is connected to an electrode **1006** of a light-emitting element. A part of a gate signal line **1003** serves as a gate electrode of the first transistor **1001**.

Next, a driving method will be explained. FIG. **5** is a diagram illustrating an operation per frame in accordance with passage of time. In FIG. **5**, the horizontal direction indicates passage of time, and the vertical direction indicates the number of scanning stages of gate signal lines.

When a light-emitting device of the present invention is used to display images, a rewrite operation and a display operation for a screen are repeated in a display period. Although the number of rewrites is not particularly limited, it is preferable that the number of rewrites be at least about 60 times per second so as not to make a viewer notice flickers. Here, a period for which a rewrite operation and a display operation are performed for a screen (one frame) is referred to as one frame period.

As shown in FIG. **5**, one frame period is divided into four sub-frames **501**, **502**, **503**, and **504** including writing periods **501***a*, **502***a*, **503***a*, and **504***a* and retention periods **501***b*, **502***b*, **503***b*, and **504***b*, respectively. A light-emitting element to which a signal for emitting light is given is made to be in an emitting state in a retention period. The ratio of the length of the retention period in each sub-frame is, the first sub-frame

501: the second sub-frame **502**: the third sub-frame **503**: the fourth sub-frame **504**=2^3:2^2:2^1:2^0=8:4:2:1. This makes 4-bit gradation possible. However, the number of bits and the number of gradations are not limited to the ones described here. For example, eight sub-frames may be provided so as to perform 8-bit gradation.

An operation in one frame period will be explained. First, in the sub-frame **501**, writing operations are sequentially performed for a first row to a last row. Consequently, the start time of writing period is different depending on the rows. In rows for which the writing period **501***a* is completed, the state is shifted sequentially into the retention period **501***b*. In the retention periods, a light-emitting element to which a signal for emitting light is given is made to be in an emitting state. In addition, in rows for which the retention period **501***b* is completed, the state is shifted sequentially into the next sub-frame **502**, and writing operations are sequentially performed for the first row to the last row as in the case of the sub-frame **501**. Such operations as described above are repeated and finish up to the retention period **504***b* of the sub-frame **504**. When the operation in the sub-frame **504** is completed, the next frame begins. Thus, a total of the time for which light is emitted in each sub-frame is emission time for each light-emitting element in one frame. By varying this emission time for each light-emitting element to have various combinations in one pixel, various display colors with different luminosity and chromaticity can be made.

As in the sub-frame **504**, when forcible termination of a retention period of a row for which writing has been already completed and which is moved into the retention period is required before writing for the last row is completed, it is preferable that an erasing period **504***c* be provided after the retention period **504***b* and a row be controlled so as to be in a non-emitting state forcibly. Then, the row forcibly made to be in the non-emitting state is kept in the non-emitting state for a certain period (this period is referred to as a non-emission period **504***d*). Then, immediately after the writing period of the last row is completed, the state is shifted sequentially into the writing period (or the next frame), starting from the first row. This makes it possible to prevent the writing period of the sub-frame **504** from overlapping with the writing period of the next sub-frame.

Although the sub-frames **501** to **504** are arranged in the order from the longest retention period to the shortest in this embodiment mode, the arrangement as in this embodiment mode is not always necessary. For example, the sub-frames **501** to **504** may be arranged in the order from the shortest retention period to the longest, or may be arranged in random order. In addition, the sub-frames may be further divided into a plurality of frames. In other words, scanning of the gate signal lines may be performed plural times while giving the same video signal.

Now, an operation of the circuit shown in FIG. **3** in a writing period and an erasing period will be explained.

First, an operation in a writing period will be explained. In the writing period, the gate signal line **911** in n-th row (n is a natural number) is electrically connected to the writing gate signal line driving circuit **913** through the switch **918**, and disconnected to the erasing gate signal line driving circuit **914**. In addition, the source signal line **912** is electrically connected to the source signal line driving circuit **915** through the switch **920**. Here, a signal is inputted into the gate of the first transistor **901** connected to the gate signal line **911** in n-th row (n is a natural number) to turn on the first transistor **901**. Then, at this time, video signals are inputted at the same time into the source signal lines **912** in the first to the last columns. It is to be noted that the video signals inputted from the source signal lines **912** in the respective columns are independent of each other. The video signal inputted from the source signal line **912** is inputted into the gate electrode of the second transistor **902** through the first transistor **901** connected to each of the source signal lines **912**. At this time, whether the light-emitting element **903** emits light or not is determined depending on the signal imputed to the second transistor **902**. For example, when the second transistor **902** is a p-channel transistor, the light-emitting element **903** emits light by inputting a Low Level signal to the gate electrode of the second transistor **902**. On the other hand, when the second transistor **902** is an n-channel transistor, the light-emitting element **903** emits light by inputting a High Level signal to the gate electrode of the second transistor **902**.

Next, an operation in an erasing period will be explained. In the erasing period, the gate signal line **911** in n-th row (n is a natural number) is electrically connected to the erasing gate signal line driving circuit **914** through the switch **919** and disconnected to the wiring gate signal line driving circuit **913**. In addition, the source signal line **912** is electrically connected to the power source **916** through the switch **920**. Here, a signal is inputted into the gate of the first transistor **901** connected to the gate signal line **911** in n-th row to turn on the first transistor **901**. Then, at this moment, erasing signals are inputted at the same time into the source signal lines **912** in the first to last columns. The erasing signal inputted from the source signal lines **912** is inputted into the gate electrode of the second transistor **902** through the first transistor **901** connected to each of the source signal lines. At this moment, current supply from the current-supply line **917** to the light-emitting element **903** is stopped by the signal inputted into the second transistor **902**. Then, the light-emitting element **903** is forcibly made to emit no light. For example, when the second transistor **902** is a p-channel transistor, the light-emitting element **903** emits no light by inputting a High Level signal to the gate electrode of the second transistor **902**. On the other hand, when the second transistor **902** is an n-channel transistor, the light-emitting element **903** emits no light by inputting a Low Level signal to the gate electrode of the second transistor **902**.

It is to be noted that, as for n-th row (n is a natural number), signals for erasing are inputted by the operation as described above in an erasing period. However, as described above, another row (referred to as m-th row (m is a natural number)) may be in a writing period while the n-th row is in an erasing period. In such a case, it is necessary to input a signal for erasing into the n-th row and input a signal for writing into the m-th row by using a source signal line in the same column. Therefore, an operation that will be explained below is preferable.

Immediately after the light-emitting element **903** in the n-th row is made to emit no light by the operation in the erasing period as explained above, the gate signal line **911** and the erasing gate signal line driving circuit **914** are made to be disconnected to each other, and the switch **920** is switched to connect the source signal line **912** and the source signal line driving circuit **915**. Then, in addition to connecting the source signal line **912** to the source signal line driving circuit **915**, the gate signal line **911** is connected to the writing gate signal line driving circuit **913**. Then, a signal is inputted selectively into the gate signal line **911** in the m-th row from the writing gate signal line driving circuit **913** to turn on the first transistor **901**, and signals for writing are inputted into the source signal lines **912** in the first to last columns from the source signal line driving circuit **915**. This signal makes the light-emitting element **903** in the m-th row be in an emitting or non-emitting state.

Immediately after the writing period for the m-th row is completed as described above, an erasing period for a (n+1)-th row is started. For that purpose, the gate signal line **911** and the writing gate signal line driving circuit **913** are made to be disconnected to each other, and the switch **920** is switched to connect the source signal line **912** and the power source **916**. Further, the gate signal line **911** is made to be disconnected to the writing gate signal line driving circuit **913**, and to be connected to the erasing gate signal line driving circuit **914**. Then, a signal is inputted selectively into the gate signal line in the (n+1)-th row from the erasing gate signal line driving circuit **914** to turn on the first transistor **901**, and an erasing signal is inputted from the power source **916**. Immediately after the erasing period for the (n+1)-th row is thus completed, a writing period for the (m+1)-th row is started. Then, an erasing period and a writing period may be repeated in the same way until an erasing period for the last row is completed.

Although a mode in which the writing period for the m-th row is provided between the erasing period for the n-th row and the erasing period for the (n+1)-th row is explained in this embodiment mode, the present invention is not limited thereto. The writing period for the m-th row may be provided between an erasing period for a (n−1)-th row and an erasing period for the n-th row as well.

In addition, in this embodiment mode, an operation is repeated, in which the erasing gate signal line driving circuit **914** and one gate signal line are made to be disconnected to each other as well as the writing gate signal line driving circuit **913** and another gate signal line are made to be connected to each other when the non-emission period **504***d* is provided as in the sub-frame **504**. This type of operation may also be performed in a frame in which a non-emission period is not particularly provided.

Embodiment Mode 3

One mode of a light-emitting device including a light-emitting element of the present invention will be described with reference to cross-sectional views in FIGS. **6**A to **6**C.

In each of FIGS. **6**A to **6**C, a box-shaped portion surrounded by a dotted line is a transistor **11** provided for driving a light-emitting element **12** of the present invention. The light-emitting element **12** is a light-emitting element of the present invention described in Embodiment Mode 1. A drain of the transistor **11** and the first electrode **13** are electrically connected to each other by a wiring **17** running through a first interlayer insulating film **16** (**16***a*, **16***b*, and **16***c*). In addition, the light-emitting element **12** is separated by a partition layer **18** from another light-emitting element that is provided adjacently. A light-emitting device having such a structure of the present invention is provided over a substrate **10** in this embodiment mode.

It is to be noted that the transistor **11** shown in each of FIGS. **6**A to **6**C is a top-gate TFT in which a gate electrode is provided on an opposite side of a substrate with a semiconductor layer as a center. However, a structure of the transistor **11** is not particularly limited. For example, a bottom-gate TFT may be used. In the case of a bottom-gate TFT, a TFT where a protective film is formed over a semiconductor layer that forms a channel (a channel-protected TFT) may be employed, or a TFT where a part of a semiconductor layer that forms a channel is depressed (a channel-etched f) may be employed.

In addition, a semiconductor layer which forms the transistor **11** may be either crystalline or amorphous, or alternatively, semi-amorphous or the like.

The following will describe a semi-amorphous semiconductor. The semi-amorphous semiconductor is a semiconductor that has an intermediate structure between amorphous and crystalline (including single-crystal or polycrystalline) structures and has a third state that is stable in terms of free energy, which includes a crystalline region that has short range order and lattice distortion. Further, a crystal grain of 0.5 to 20 nm is included in at least a region in a film of the semi-amorphous semiconductor. Raman spectrum is shifted to a wave number side lower than 520 cm^{-1}. The diffraction peaks of (111) and (220), which are believed to be derived from silicon crystal lattice, are observed by the X-ray diffraction. The semi-amorphous semiconductor contains hydrogen or halogen of at least 1 atomic % or more for terminating dangling bonds. The semi-amorphous semiconductor is also referred to as a so-called microcrystalline semiconductor. A microcrystalline semiconductor can be formed by glow discharge decomposition (using plasma CVD) with a gas containing silicon selected from SiH_4, Si_2H_6, SiH_2Cl_2, $SiHCl_3$, $SiCl_4$, or SiF_4. Such a gas containing silicon also be diluted with H_2, or a mixture of H_2 and one or more of rare gas elements of He, Ar, Kr, and Ne. The dilution ratio is set to be in a range of 1:2 to 1:1000. The pressure is set to be approximately in the range of 0.1 to 133 Pa. The power frequency is set to be 1 to 120 MHz, preferably, 13 to 60 MHz. The substrate heating temperature may be set to be 300° C. or lower, more preferably, 100 to 250° C. As for impurity elements contained in the film, each concentration of impurities for atmospheric constituents such as oxygen, nitrogen and carbon is preferably set to be $1\times10^{20}/cm^3$ or lower. In particular, the oxygen concentration is set to be $5\times10^{19}/cm^3$ or less, preferably, $1\times10^{19}/cm^3$ or less.

Further, as specific examples of a crystalline semiconductor layer, a semiconductor layer formed of single-crystal or polycrystalline silicon, or silicon-germanium is given, which may be formed by laser crystallization or may be formed by crystallization with a solid-phase growth method using an element such as nickel.

In the case of using an amorphous substance, for example, amorphous silicon to form the semiconductor layer, it is preferable that the light-emitting device have a circuit in which the transistor **11** and other transistors (transistors constituting a circuit for driving the light-emitting element) are all n-channel transistors. Other than that case, the light-emitting device may have a circuit including one of an n-channel transistor and a p-channel transistor or may have a circuit including both of an n-channel transistor and a p-channel transistor.

Further, the first interlayer insulating film **16** may be multilayered as shown in FIGS. **6**A to **6**C, or may be a single layer. It is to be noted that the first interlayer insulating film **16***a* contains an inorganic substance such as silicon oxide or silicon nitride, and the first interlayer insulating film **16***b* contains acrylic, siloxane (siloxane is a compound which its skeleton structure is structured by a bond between silicon (Si) and oxygen (O), and has an organic group such as a fluoro group or an alkyl group as a substituent), or a substance such as silicon oxide that can be formed by being coated. In addition, the first interlayer insulating film **16***c* includes a silicon nitride film containing argon (Ar). The substances constituting each of the layers are not particularly limited; therefore, substances other than the substances mentioned here may also be used. Moreover, a layer containing a substance other than these substances may also be combined. In this way, both of an inorganic substance and an organic substance, or one of an inorganic substance and an organic substance may be used to form the first interlayer insulating film **16**.

As for the partition layer **18**, it is preferable that an edge portion have a shape varying continuously in curvature radius. In addition, acrylic, siloxane, resist, silicon oxide or

the like is used to form the partition layer **18**. One or both of an inorganic substance and an organic substance may be used to form the partition layer **18**.

In each of FIGS. **6**A and **6**C, only the first interlayer insulating film **16** is provided between the transistor **11** and the light-emitting element **12**. However, as shown in FIG. **6**B, a second interlayer insulating film **19** (**19***a* and **19***b*) may be provided in addition to the first interlayer insulating film **16** (**16***a* and **16***b*). In the light-emitting device shown in FIG. **6**B, the first electrode **13** is connected to the wiring **17**, by passing through the second interlayer insulating film **19**.

The second interlayer insulating film **19** may be multilayered or a single layer as in the case of the first interlayer insulating film **16**. The second interlayer insulating film **19***a* contains a substance such as acrylic, siloxane, or silicon oxide or the like that can be formed by being coated. In addition, the second interlayer insulating film **19***b* includes a silicon nitride film containing argon (Ar). The substances constituting the respective layers are not particularly limited; therefore, substances other than the substances mentioned here may also be used. Moreover, a layer containing a substance other than these substances may also be combined. In this way, both of an inorganic substance and an organic substance, or a film made of one of an inorganic substance and an organic substance may be used to form the second interlayer insulating film **19**.

In the light-emitting element **12**, in a case where both of the first electrode and the second electrode are formed by using a light transmitting substance, emitted light can be extracted from both of the first electrode **13** side and the second electrode **14** side as indicated by outline arrows of FIG. **6**A. In the case where only the second electrode **14** is formed by using a light transmitting substance, emitted light can be extracted from only the second electrode **14** side as indicated by an outline arrow of FIG. **6**B. In this case, it is preferable that the first electrode **13** be formed by using a highly reflective material, or a film composed of a highly reflective material (a reflective film) be provided below the first electrode **13**. Further, in the case where only the first electrode **13** is formed by using a light transmitting substance, emitted light can be extracted from only the first electrode **13** side as indicated by an outline arrow of FIG. **6**C. In this case, it is preferable that the second electrode **14** be formed by using a highly reflective material, or a reflective film be provided above the second electrode **14**.

In addition, a layer **15** may be stacked so that the light-emitting element **12** is operated when a voltage is applied so as to make the potential of the second electrode **14** higher than that of the first electrode **13**. Alternatively, the layer **15** may be stacked so that the light-emitting element **12** is operated when a voltage is applied so as to make the potential of the second electrode **14** lower than that of the first electrode **13**. The transistor **11** is an n-channel transistor in the former case, and the transistor **11** is a p-channel transistor in the latter case.

In this embodiment mode, an active type light-emitting device that controls driving of a light-emitting element by a transistor has been described as in the above. However, the light-emitting element may also be a passive type that drives a light-emitting element without particularly providing an element for driving such as a transistor. FIG. **7** is a perspective view of a passive type light-emitting device manufactured by applying the present invention. The light-emitting device in FIG. **7** includes a light-emitting element of the present invention having a structure where a layer **955** including a light-emitting layer and the like is provided between an electrode **952** and an electrode **956**, over a substrate **951**. End portions of the electrode **952** are covered with an insulating layer **953**. Further, a partition layer **954** is provided over the insulating layer **953**. Side walls of the partition layer **954** are sloped so that a distance between one side wall and the other becomes shorter towards a substrate surface. In other words, a cross-section in a short side direction of the partition layer **954** has a trapezoidal shape, for which a bottom side (a side in the same direction as a plane direction of the insulating layer **953**, and is in contact with the insulating layer **953**) is shorter than an upper side (a side in the same direction as the plane direction of the insulating layer **953**, and is not in contact with the insulating layer **953**). In this manner, by providing the partition layer **954**, malfunctioning of a light-emitting element due to electrostatic discharge and the like can be prevented. Also, in a passive type light-emitting device, by including a light-emitting element of the present invention that operates with low driving voltage, driving with low power consumption is possible.

Embodiment Mode 4

Since a light-emitting device using a light-emitting element of the present invention as a pixel or a light source can be operated with low power consumption, an electronic device that can be operated with low power consumption can be obtained by using such a light-emitting device for a display portion.

An example of an electronic device mounted with a light-emitting device to which the present invention is applied, is shown in each of FIGS. **8**A to **8**C.

FIG. **8**A is a personal computer manufactured by applying the present invention, which includes a main body **5521**, a housing **5522**, a display portion **5523**, a keyboard **5524**, and the like. The personal computer which can be operated with low power consumption can be completed by incorporating, in the display portion, a light-emitting device (for example, a light-emitting device including a structure such as those described in Embodiment Modes **3** and **4**) including the light-emitting element of the present invention as described in Embodiment Mode 1 as a pixel. Further, the personal computer can also be completed by incorporating as a backlight a light-emitting device using the light-emitting element of the present invention as a light source. Specifically, a lighting device in which a liquid crystal device **5512** and a light-emitting device **5513** are fit into a housing **5511** and a housing **5514**, may be incorporated as a display portion as shown in FIG. **9**. Note that in FIG. **9**, an external input terminal **5515** is attached to the liquid crystal device **5512**, and an external input terminal **5516** is attached to the light-emitting device **5513**.

FIG. **8**B is a telephone set manufactured by applying the present invention, which includes a main body **5552**, a display portion **5551**, an audio output portion **5554**, an audio input portion **5555**, operation switches **5556** and **5557**, an antenna **5553**, and the like. The telephone set which can be operated with low power consumption can be completed by incorporating a light-emitting device including the light-emitting element of the present invention as the display portion.

FIG. **8**C is a television set manufactured by applying the present invention, which includes a display portion **5531**, a housing **5532**, a speaker **5533**, and the like. The television set which can be operated with low power consumption can be completed by incorporating a light-emitting device including the light-emitting element of the present invention as the display portion.

As in the above, the light-emitting device of the present invention is extremely suitable to be used in display portions for various electronic devices. Note that the electronic device

is not limited to those mentioned in this embodiment mode, and may be other electronic devices as a navigation device and the like.

EXAMPLE 1

One example of the present invention is described with reference to FIG. **10**.

In Example 1, twenty one light-emitting elements which had different thickness of mixed layers in which a hole transporting substance and a metal oxide were mixed, and in which each of the substances had a different volume percentage were manufactured, and the current efficiency (cd/A) and power efficiency (lm/W) of each light-emitting element were measured. Thicknesses of mixed layers and volume percentages of metal oxides with respect to volumes of the mixed layers (mixing rate) [vol %] in the respective light-emitting elements are shown in Table 1. In this example, NPB was used as the hole transporting substance and molybdenum oxide was used as the metal oxide.

TABLE 1

Light-emitting element	Thickness (nm)	Volume percentage (vol %)
(1)	60	7
(2)	90	7
(3)	120	7
(4)	150	7
(5)	180	7
(6)	210	7
(7)	240	7
(8)	60	10
(9)	90	10
(10)	120	10
(11)	150	10
(12)	180	10
(13)	210	10
(14)	240	10
(15)	60	13
(16)	90	13
(17)	120	13
(18)	150	13
(19)	180	13
(20)	210	13
(21)	240	13

First, a manufacturing method of a light-emitting element will be described. The respective light-emitting elements have the same structure except for the thickness of the mixed layer and the volume percentage of the metal oxide with respect to the volume of the mixed layer.

As shown in FIG. **10**, a first electrode **301** was formed using indium tin oxide to have a thickness of 110 nm over a substrate **300**. At this time, a sputtering method was adopted to form the first electrode **301**.

Then, a first layer **311** including NPB and molybdenum oxide was formed over the first electrode **301** by a co-evaporation method. Note that molybdenum trioxide; especially, of molybdenum oxides was used to form the first layer **311** as an evaporation material. The thicknesses of the first layers **311** in the respective light-emitting elements were set at values shown in Table 1. The volume percentages of molybdenum oxides were also set at values shown in Table 1. It is noted that "co-evaporation" means an evaporation process in which raw materials are evaporated from plural evaporation sources provided in one treatment chamber and the evaporated raw materials are deposited on objects to be processed to form layers in which plural substances are mixed.

Then, a second layer **312** was formed using NPB over the first layer **311** by an evaporation method. A thickness of the second layer **312** was set 10 nm. The second layer **312** served as a hole transporting layer, when each of the light-emitting elements was driven.

Next, a third layer **313** including Alq_3 and coumarin 6 was formed over the second layer **312** by a co-evaporation method. A thickness of the third layer **313** was set 40 nm. In addition, a weight ratio of Alq_3 to coumarin 6 was set at 1:0.01 (a molar ratio was 1:0.013)(=Alq_3 to coumarin 6). Thus, coumarin 6 was dispersed in the layer formed from Alq_3. The thusly formed third layer **313** served as a light-emitting layer when each of the light-emitting elements was driven.

A fourth layer **314** was formed using Alq_3 over the third layer **313** by an evaporation method. A thickness of the fourth layer **314** was set at 30 nm. The fourth layer **314** served as an electron transporting layer, when each of the light-emitting elements was driven.

A fifth layer **315** was formed using lithium fluoride over the fourth layer **314** by an evaporation method. A thickness of the fifth layer **315** was set at 1 nm. The fifth layer **315** served as an electron injecting layer, when each of the light-emitting elements was driven.

Then, a second electrode **302** was formed using aluminum over the fifth layer **315** by an evaporation method to have a thickness of 200 nm.

As described above, voltage was applied to each of the manufactured light-emitting elements such that a potential of the first electrode **301** became higher than that of the second electrode **302**, and operation properties of the light-emitting elements were measured. The measurement results are shown in FIGS. **11** to **14**. FIG. **11** is a graph in which after the light-emitting elements (**1**) to (**21**) were made to emit light at 1000 cd/m^2 and current efficiencies were measured, the current efficiencies [cd/A] (vertical axis) at 1000 cd/m^2 with respect to thicknesses of the first layers **311** [nm] (horizontal axis) were plotted. FIG. **12** is a graph in which after the light-emitting elements (**1**) to (**21**) were made to emit light at 1000 cd/m^2 and power efficiencies were measured, the power efficiencies [lm/W] (vertical axis) at 1000 cd/m^2 with respect to thicknesses of the first layers **311** [nm] (horizontal axis) were plotted. Note that in the light-emitting elements manufactured in Example 1, green emission derived from coumarin 6 was obtained.

In FIGS. **11** and **12**, the round black marks which are plotted show results for the light-emitting elements (**1**) to (**7**), in which the volume percentage of molybdenum oxide in the first layer **311** is 7 vol %, the square black marks which are plotted show results for the light-emitting elements (**8**) to (**14**), in which the volume percentage of molybdenum oxide in the first layer **311** is 10 vol %, and the triangular black marks which are plotted show results for the light-emitting elements (**15**) to (**21**), in which the volume percentage of molybdenum oxide in the first layer **311** is 13 vol %.

As shown in FIGS. **11** and **12**, the current efficiencies and power efficiencies are highest when the first layers **311** are 120 to 180 nm thick (in other words, when the distance from the third layer **313** serving as a light-emitting layer to the first electrode **301** is 130 to 190 nm), in each light-emitting element with a different volume percentage.

FIG. **13** is a graph in which after the light-emitting elements (**1**) to (**21**) were made to emit light at 10 mA/cm^2 and current efficiencies were measured, the current efficiencies [cd/A] (vertical axis) at 10 mA/cm^2 with respect to thicknesses of the first layers **311** [nm] (horizontal axis) were plotted. FIG. **14** is a graph in which after the light-emitting elements (**1**) to (**21**) were made to emit light at 10 mA/cm^2 and

power efficiencies were measured, the power efficiencies [lm/W] (vertical axis) at 10 mA/cm^2 with respect to thicknesses of the first layers **311** [nm] (horizontal axis) were plotted.

In FIGS. **13** and **14**, as in the case where the light-emitting elements were made to emit light at 10 mA/cm^2, it can be seen that the current efficiencies and power efficiencies were highest when the first layers **311** were 150 nm thick.

It can be considered that variation in power efficiency dependent on thicknesses of the first layers **311** as described above are a phenomenon primarily caused by a change in the amount of light emitted to outside from the light-emitting elements, which is a result of a change of the distance between the third layer **313** serving as a light-emitting layer and the electrode (i.e., a change of an optical path length) made by changing the thickness of the first layer **311**.

EXAMPLE 2

In Example 2, in addition to the light-emitting elements (**1**) to (**21**) manufactured in Example 1, four light-emitting elements (**22**), (**23**), (**24**) and (**25**) were manufactured, in which volume percentage in a mixed layer in which a hole transporting substance and a metal oxide were mixed (volume percentage of the metal oxide with respect to the volume of the mixed layer) was 4 vol %, and thicknesses of the mixed layers (first layers **311**) were 60 nm, 90 nm, 120 nm, and 150 nm, respectively.

Structures other than the mixed layers were formed similarly to the light-emitting elements (**1**) to (**21**), and thus the description in Example 1 may be referred to for description of the manufacturing method of the light-emitting elements (**22**) to (**25**).

FIGS. **15**A to **15**D show current-voltage characteristics obtained when the light-emitting elements (**1**) to (**4**), (**8**) to (**11**), (**15**) to (**18**) and (**22**) to (**25**) were made to emit light. FIG. **15**A shows current-voltage characteristics of the light-emitting elements (**22**) to (**25**) having a volume percentage of 4 vol %. FIG. **15**B shows current-voltage characteristics of the light-emitting elements (**1**) to (**4**) having a volume percentage of 7 vol %. FIG. **15**C shows current-voltage characteristics of the light-emitting elements (**8**) to (**11**) having a volume percentage of 10 vol %. FIG. **15**D shows current-voltage characteristics of the light-emitting elements (**15**) to (**18**) having a volume percentage of 13 vol %. Note that in FIGS. **15**A to **15**D, vertical axes show current (mA) and horizontal axes show voltage (V).

As can be seen FIGS. **15**A to **15**D, it can be considered that as the volume percentages rise (in other words, as a concentration of molybdenum oxide, which is one of metal oxides, becomes higher), a difference of current-voltage characteristics dependent on the thickness of the mixed layer becomes smaller. Thus, it can be seen that the volume percentage of molybdenum oxide with respect to the mixed layer is preferably set higher than 4 vol % especially, in order to manufacture a light-emitting element in which a voltage to be applied for driving so that a constant current flows hardly changes depending on the thickness of the mixed layer.

The present application is based on Japanese Patent Application serial No. 2005-167620 filed on Jun. 8, 2005 in Japanese Patent Office, the entire contents of which are hereby incorporated by reference.

What is claimed is:

1. A light-emitting device comprising a light-emitting element, the light-emitting element comprising:

a layer comprising a hole transporting substance and a metal oxide having an electron accepting property to the hole transporting substance over a first electrode;

a light-emitting layer comprising a light-emitting substance over the layer;

an electron transporting layer comprising an electron transporting substance over the light-emitting layer; and

a second electrode over the light-emitting layer,

wherein the layer has a region whose thickness is 120 to 180 nm,

wherein the metal oxide is included in the region at a concentration of 7 vol % to 13 vol % with respect to the hole transporting substance, and

wherein a difference of hole mobility of the hole transporting substance and electron mobility of the electron transporting substance is 1000 or less.

2. The light-emitting device according to claim **1**, wherein the metal oxide is molybdenum oxide.

3. The light-emitting device according to claim **1**, wherein the metal oxide is molybdenum trioxide.

4. The light-emitting device according to claim **1**, wherein the light-emitting layer emits green light.

5. The light-emitting device according to claim **1**, wherein a total thickness between the light-emitting layer and the first electrode is in a range of 120 to 300 nm.

6. An electronic device comprising the light-emitting device according to claim **1**, wherein the electronic device is selected from the group consisting of a personal computer, a portable phone, a television, a navigation system, and a lighting system.

7. A light-emitting device comprising a light-emitting element, the light-emitting element comprising:

a layer comprising a hole transporting substance and a metal oxide having an electron accepting property to the hole transporting substance over a first electrode;

a light-emitting layer comprising a light-emitting substance over the layer;

an electron transporting layer comprising an electron transporting substance over the light-emitting layer; and

a second electrode over the light-emitting layer,

wherein the layer has a region whose thickness is 120 to 180 nm,

wherein a molar ratio of the metal oxide to the hole transporting substance in the region is 1:4 to 2:4 metal oxide: hole transporting substance, and

wherein a difference of hole mobility of the hole transporting substance and electron mobility of the electron transporting substance is 1000 or less.

8. The light-emitting device according to claim **7**, wherein the metal oxide is molybdenum oxide.

9. The light-emitting device according to claim **7**, wherein the metal oxide is molybdenum trioxide.

10. The light-emitting device according to claim **7**, wherein the light-emitting layer emits green light.

11. The light-emitting device according to claim **7**, wherein a total thickness between the light-emitting layer and the first electrode is in a range of 120 to 300 nm.

12. An electronic device comprising the light-emitting device according to claim **7**, wherein the electronic device is selected from the group consisting of a personal computer, a portable phone, a television, a navigation system, and a lighting system.

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